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Research on Hedging of Energy Index Based on Portfolio Strategy of Stock Index and Crude Oil Futures

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Abstract

In recent years, the sharp fluctuations in international crude oil prices have had a significant impact on the stock prices of China's energy industry. With the growing trend of commodity financialization, energy assets face not only traditional oil price volatility risks but also financial factors driven by speculative trading, index fund investments, and cross-border capital flows. Consequently, the demand for risk management through hedging of energy assets has been increasing. Traditionally, investors have primarily relied on stock index futures to hedge energy stocks; however, single stock index futures are insufficient to effectively mitigate systematic risks arising from oil price fluctuations, let alone cover the composite risks introduced by financialization. This paper adopts a portfolio hedging framework combining stock index futures and crude oil futures to investigate hedging strategies for the CSI 300 Energy Index, CSI 500 Energy Index, and CSI 800 Energy Index. This paper compares the performance of single-futures hedging and portfolio futures hedging, with particular attention to the incremental value of crude oil futures in portfolio hedging. Using daily data from March 2018 to September 2025, this paper employs a rolling window approach to estimate optimal hedge ratios and out-of-sample hedging performance. The results demonstrate that portfolio futures hedging outperforms single-futures hedging, with the CSI 500 Energy Index exhibiting the most pronounced portfolio hedging effect. Crude oil futures provide a significant marginal contribution in portfolio hedging, with a marginal contribution of approximately 30% (CSI 300 Energy Index) and 12.77% (CSI 500 Energy Index). This study constructs an analytical framework for portfolio hedging of energy indices using futures, introduces the marginal contribution metric to quantify the incremental value of crude oil futures, and enriches the research scope of multi-futures portfolio hedging, offering actionable decision-making references for energy industry investors and regulators.

Keywords

Energy Index, Portfolio Hedging, Crude Oil Futures, Stock Index Futures, Marginal Contribution

1. Introduction

Energy price fluctuations exert significant impacts on macroeconomic stability and financial markets. In recent years, the international crude oil market has experienced severe turbulence: the COVID-19 pandemic in 2020 caused WTI crude oil futures to briefly fall into negative territory, while the Russia-Ukraine conflict in 2022 drove oil prices above $130 per barrel, with ongoing geopolitical risks continuing to disrupt global supply chains. These extreme events have not only affected the cost structure of the real economy but also significantly influenced the stock price performance of listed energy companies in China, leading to increased volatility and expanded risk exposure for investors.

Listed companies in China's energy industry encompass traditional enterprises in petroleum, coal, and power sectors, as well as new energy enterprises. These firms generally exhibit characteristics such as capital intensity, high operating leverage, and significant profitability sensitivity to energy prices. Taking the petroleum industry as an example, rising oil prices benefit upstream exploration enterprises but increase costs for downstream refining and chemical enterprises, with the opposite holding true when prices decline. Consequently, energy industry stock prices are driven not only by systematic factors such as macroeconomic conditions and monetary policy but also directly by fluctuations in international energy prices. Investors typically employ stock index futures to hedge energy industry stocks; however, stock index futures primarily reflect overall market systematic risk and are ineffective in hedging risks specific to energy prices. When oil prices fluctuate significantly while the broader stock market remains stable, energy stocks may still experience sharp movements, substantially diminishing the effectiveness of hedging strategies relying solely on stock index futures. In recent years, the growing trend of commodity financialization has profoundly altered the risk structure of energy markets. Chinese energy industry stocks face not only traditional oil price volatility risk and stock market systematic risk but also composite risk shocks from financialization. Therefore, single futures instruments—whether stock index futures or crude oil futures—are insufficient to comprehensively cover the diversified risks facing energy stocks, rendering portfolio hedging strategies combining stock index futures and crude oil futures theoretically well-founded.

China's crude oil futures were launched on the Shanghai International Energy Exchange (INE) on March 26, 2018, denominated in RMB and open to global investors. INE crude oil futures have become the world's third-largest crude oil futures contract, providing energy industry investors with direct instruments for hedging oil price risk and enabling portfolio hedging strategies combining stock index futures and crude oil futures. At the practical level, several critical questions arise: How can investors optimally construct hedging portfolios utilizing stock index futures and crude oil futures? Which is more effective, single-futures hedging or portfolio futures hedging? Do hedging effectiveness differ across energy indices of varying scales? What is the incremental value of crude oil futures in portfolio hedging? Addressing these questions holds substantial practical significance for risk management in China's energy industry.

Based on the above background, the energy stocks face a composite risk structure comprising broad stock market systematic risk and energy commodity-specific risk. While stock index futures are effective hedges against systematic risk, and crude oil futures address commodity-specific risk, neither instrument alone can comprehensively cover all the risk. Portfolio hedging that combines stock index futures and crude oil futures therefore offers a theoretically superior risk management framework. Based on this theoretical foundation and the empirical context of China's energy futures market, this paper proposes the following research hypotheses:

H1: Portfolio hedging combining stock index futures and crude oil futures outperforms single-futures hedging in hedging effectiveness.

H2: Crude oil futures exhibit differentiated marginal contributions across energy indices of different market capitalization scales in portfolio hedging.

H3: Portfolio hedging performance remains relatively stable over the sample period, whereas single-futures hedging effectiveness is more susceptible to market state variations.

This paper utilizes CSI 300 Index Futures (IF), CSI 500 Index Futures (IC), and Shanghai International Energy Exchange crude oil futures (SC) to hedge the CSI 300 Energy Index, CSI 500 Energy Index, and CSI 800 Energy Index, respectively. For each index, we construct three hedging strategies: single stock index futures hedging, single crude oil futures hedging, and combined portfolio hedging, systematically comparing the risk hedging effects across different strategies. The contributions of this paper are threefold:

First, theoretical contribution: This paper incorporates the commodity financialization perspective into energy index hedging analysis, constructs a portfolio hedging framework combining stock index futures and crude oil futures, and introduces the Marginal Contribution (MC) metric to quantify the incremental value of crude oil futures in portfolio hedging for the first time. This enriches the research on multi-futures portfolio hedging and provides novel empirical support for related theories.

Second, practical contribution: The conclusions offer differentiated risk management strategy guidance for energy industry investors of varying scales. For CSI 500 Energy Index investors, portfolio futures hedging can significantly reduce portfolio risk; for CSI 300 Energy Index investors, the marginal contribution of crude oil futures is particularly prominent (approximately 30% efficiency improvement).

Third, policy contribution: The examination of the hedging function of Shanghai crude oil futures provides decision-making references for regulators to optimize futures market structure, promote energy derivatives innovation, and enhance the capacity of futures markets to serve the real economy.

The remainder of this paper is organized as follows: Section 2 reviews the literature on hedging theory, energy futures hedging, commodity financialization, China's energy futures market, and portfolio hedging strategies. Section 3 establishes the model framework, including portfolio hedging modeling, marginal contribution analysis, and the dynamic rolling window method. Section 4 describes the empirical data, and descriptive statistics. Section 5 presents and analyzes the empirical results. Section 6 concludes with policy recommendations and research limitations.

2. Literature Review

Hedging constitutes the core mechanism of financial risk management, with its essence lying in reducing portfolio value fluctuations by establishing positions opposite to the risk exposure of hedged assets. From the perspective of theoretical evolution, hedging has undergone a development process from static to dynamic and from single to portfolio. Early traditional theories emphasized full hedging, positing that operating futures and spot in opposite directions at a 1:1 ratio could eliminate risk (Working, 1953). However, due to the existence of basis risk, full hedging is difficult to achieve, thus giving rise to the minimum-variance hedging model, which aims to minimize risk (Johnson, 1960; Stein, 1976; Ederington, 1979). As market conditions change rapidly, the limitations of static models have emerged, and dynamic hedging methods have developed, allowing real-time adjustment of the hedging ratio based on market fluctuations. In recent years, sharp fluctuations in energy prices have spurred the rise of multi-futures portfolio hedging, which involves simultaneously using multiple instruments such as stock index futures and crude oil futures to conduct composite hedging on asset portfolios. Concurrently, the financialization trend of commodities has profoundly altered the linkage structure between energy markets and financial markets, making the risk sources facing energy stocks more complex and posing new requirements for the design of portfolio hedging strategies.

This paper systematically reviews the relevant literature from five dimensions: the development of hedging theory, energy futures hedging, commodity financialization, China's energy futures market and futures instruments, and portfolio hedging strategies, thereby clarifying the theoretical positioning and innovative contributions of this study.

2.1. Development of Hedging Theory

The development of hedging theory has evolved from traditional hedging to minimum-variance hedging and then to dynamic hedging. Working (1953) first proposed the traditional hedging theory, emphasizing locking prices through opposite operations in futures and spot markets, with its core focus on basis risk management. Johnson (1960) and Stein (1976) incorporated the hedging problem into the portfolio optimization framework, proposing the concept of the Minimum-Variance Hedge Ratio (MVHR), which laid the foundation for modern hedging theory. Ederington (1979) further formalized the hedging problem as a portfolio optimization problem, determining the optimal hedging ratio by minimizing the variance of the hedging portfolio's return. This framework became an important starting point for subsequent research. In the measurement of hedging ratios, Ordinary Least Squares (OLS) is the most classic static estimation method, with advantages such as a solid theoretical foundation, simple computation, and strong interpretability of results.

However, OLS assumes a constant hedging ratio, which does not match the time-varying characteristics of the covariance structure in actual markets (Fabozzi & Fabozzi, 2022). Buyukkara et al. (2022) empirically demonstrate that there are significant differences in the in-sample and out-of-sample performance of different hedging models, with simple OLS models sometimes outperforming complex dynamic models. To overcome static limitations, dynamic hedging methods have emerged, with their core being the real-time adjustment of hedging ratios according to market conditions. Zhang and Choudhry (2015) use GARCH models combined with rolling prediction methods to confirm the effectiveness of dynamic hedging in agricultural futures markets. Wang et al. (2019) employ a time-varying Markov DCC-GARCH model and find that the estimated hedging ratios are more stable. Xu (2019) identifies the rolling window method as an important technical path to achieve dynamic hedging, capable of capturing the time-varying characteristics of price relationships. Rastogi et al. (2024) use DCC-GARCH and BEKK-GARCH models to confirm that time-varying conditional correlation models can better characterize dynamic correlations between assets. Basher and Sadorsky (2016) further note that in cross-market hedging, crude oil is the most effective single hedging instrument for emerging market stocks, but DCC-GARCH models outperform symmetric DCC models in capturing asymmetric correlations. In summary, OLS is simple and feasible but exhibits biases under time-varying correlations, while dynamic models can improve time-varying adaptability, but the specific effectiveness depends on market characteristics, hedging horizons, and the match between model complexity and sample size.

2.2. Energy Futures Hedging Research

Energy futures hedging is an important branch of hedging research, involving various energy products such as crude oil, natural gas, heating oil, and gasoline. Sharp fluctuations in energy prices have made energy futures hedging a focus of attention for energy companies and investors. Ghoddusi and Emamzadehfard (2017) study the optimal hedging problem in the US natural gas market, examining the impact of futures contract maturity and cointegration relationships on hedging effectiveness. Halkos and Tsirivis (2019) conduct a systematic review of optimal hedging strategies for energy commodities, noting that the estimation of hedging ratios in crude oil markets requires more reliable methods. Xu and Lien (2020) apply the Generalized Autoregressive Score (GAS) model to crude oil and natural gas futures hedging, finding that the GAS framework can effectively capture the marginal distribution characteristics of spot and futures returns. Furió and Torró (2020) study optimal hedging under biased energy futures markets, discovering that time-varying negative futures basis can be predicted and used to improve hedging strategies.

Mensi et al. (2021) study dynamic frequency relationships and volatility spillover effects among energy futures markets such as natural gas, crude oil, gasoline, and heating oil, finding that natural gas assets can provide better diversification benefits for portfolios. Shrestha et al. (2018) propose the Quantile Hedge Ratio (QHR) method, extending traditional minimum-variance hedge ratios to different quantile levels, and find that hedging ratios in energy markets differ significantly across quantiles, implying that risk managers should adopt different hedging ratios according to different risk preference levels. Basher and Sadorsky (2016) further demonstrate that in cross-market hedging, crude oil is one of the most effective single hedging instruments for emerging market stocks, but dynamic models (such as ADCC-GARCH) outperform symmetric models in capturing asymmetric correlations. However, the above studies mostly focus on single-futures hedging of underlying assets by single futures varieties, without considering the potential simultaneous impact of multiple systematic risks on underlying assets, nor incorporating the composite risk (stock market systematic risk + commodity-specific risk) faced by energy stocks into a unified analytical framework.

2.3. Commodity Financialization and Energy Market Risk

In recent years, the trend of commodity financialization has become increasingly significant, profoundly changing the risk structure of energy markets and the risk attributes of energy stocks. Tang and Xiong (2012) find that since the early 2000s, with the rapid growth of index investments in commodity futures markets, correlations among US commodity futures prices have significantly increased, particularly for commodities included in major commodity indices such as GSCI and DJ-UBS. This "financialization" process explains the synchronized price surges and crashes of unrelated commodities during 2006-2008. Cheng and Xiong (2014) further point out that financialization has changed three fundamental mechanisms in commodity markets: storage, risk sharing, and information discovery. Basak and Pavlova (2016) construct the first general equilibrium model of financialization, finding that the prices, volatilities, and correlations of all commodity futures increase with the degree of financialization, but commodities included in major indices are significantly more affected than non-index commodities. Financialization mechanically increases correlations between stocks and commodities through the rebalancing behavior of institutional investors, transmitting financial market shocks not only to futures prices but also to physical spot prices and inventory levels.

Henderson, Pearson, and Wang (2015) provide new evidence on financialization, finding that index investments have significant impacts on commodity futures prices. Sockin and Xiong (2015) explain the financialization effects in commodity markets from the perspective of information frictions. Goldstein and Yang (2022) study the impact of financialization on information transmission, finding that financialization exacerbates information overload in commodity markets. Wang et al. (2021) study financialization and cross-market information transmission. Bianchi, Fan, and Todorova (2020) find that financialization has complex effects on hedging effectiveness. Baker (2021) studies the financialization of storable commodities. These studies demonstrate that financialization not only increases the volatility of energy commodity prices but also enhances the linkage between energy stocks and crude oil, and between energy stocks and the stock market, making single futures instruments insufficient to comprehensively cover the composite risks faced by energy stocks. Therefore, portfolio hedging strategies combining stock index futures and crude oil futures, simultaneously hedging systematic risk and commodity-specific risk, possess a solid theoretical foundation.

2.4. China's Energy Futures Market and Futures Instruments

China's crude oil futures were launched on the Shanghai International Energy Exchange (INE) on March 26, 2018, and have become the world's third-largest crude oil futures contract. The introduction of INE crude oil futures has provided energy industry investors with direct instruments for hedging oil price risk and has offered new objects for related academic research. Lv, Yang, and Fang (2020) are the first to examine the asset allocation improvement effects of INE crude oil futures on China petrochemical-related stocks, finding that INE futures provide effective hedging instruments for petrochemical-related stocks, with portfolios including INE futures significantly outperforming stock-only portfolios in risk-adjusted returns. Li, Huang, and Li (2021) systematically evaluate the effectiveness of Chinese crude oil futures as hedging instruments, employing DCC-GARCH and ADCC models to capture time-varying correlations, and find that the hedging effectiveness of Chinese crude oil futures exhibits asymmetric characteristics across different market states—significantly enhanced during bear markets and extreme volatility periods. Wu, Miao, Zhu, and Li (2022) specifically study the optimal hedge ratio of Shanghai crude oil futures, using the minimum-variance framework combined with Copula models, and find that different Copula functions have significant effects on hedge ratio estimation.

In terms of stock index futures, CSI 300 Index Futures (IF) and CSI 500 Index Futures (IC) correspond to systematic risks of stock markets of different market capitalization scales, providing important instruments for investors to hedge stock market risk. Hou, Li, and Wen (2019) employ DCC-GARCH combined with semi-nonparametric distribution methods to study volatility spillover effects between Chinese fuel oil futures and stock index futures, finding significant risk transmission mechanisms between the two types of futures. The above studies indicate that both Chinese crude oil futures and stock index futures have basic price discovery and risk transfer functions, but few studies have systematically compared both within a unified portfolio hedging framework.

2.5. Portfolio Hedging Strategies with Stock Index and Futures

Portfolio hedging refers to the simultaneous use of two or more futures contracts during the hedging process to achieve more comprehensive and refined risk coverage of hedged assets. Its theoretical foundation stems from Modern Portfolio Theory (MPT), with the core idea of reducing overall portfolio risk through asset diversification. Moschini and Myers (2002) study the testing of constant hedge ratios in commodity markets, providing theoretical references for portfolio hedging ratio estimation.

Feng and Cui (2022) conduct the study most directly related to this paper. They employ crude oil futures (CL) and S&P 500 stock index futures (SP) to conduct portfolio hedging of the AMEX Oil Index (XOI), comparing direct hedging and cross-hedging effects. Their findings reveal that in the direct hedging context, dual-futures hedging struggles to outperform single-futures hedging; however, in the cross-hedging context (i.e., energy index hedging), dual-futures hedging significantly outperforms single-futures hedging, because dual-futures instruments can better describe the correlation structure with the underlying index, thereby offsetting the disadvantage of transaction costs. Cui and Feng (2020) further study the relationship between portfolio hedging and utility maximization, finding that portfolio hedging outperforms single hedging under both minimum-variance and expected utility maximization frameworks. The above studies provide direct empirical support for this paper's adoption of portfolio hedging of energy indices using stock index futures and crude oil futures. However, these studies focus on US markets, and no literature has yet applied the portfolio hedging framework to Chinese energy indices, nor quantified the marginal contribution of crude oil futures in portfolio hedging.

In summary, existing research exhibits deficiencies in the following aspects, providing clear entry points for this study:

First, theoretical gap: The absence of a commodity financialization perspective. Existing energy hedging research mostly departs from traditional supply-demand perspectives, neglecting the profound impact of financialization on the risk structure of energy stocks. Financialization not only increases the volatility of energy commodities but also enhances the linkage between energy stocks and the stock market, and between energy stocks and crude oil, making single futures instruments insufficient to cover the composite risks of energy stocks. This paper incorporates the financialization background into the analytical framework, providing a more solid theoretical foundation for portfolio hedging strategies.

Second, methodological gap: Insufficient localization of the portfolio hedging framework. Although Feng and Cui (2022) and others have confirmed the effectiveness of portfolio hedging in US markets, China's energy market institutional background, market structure, and investor behavior differ significantly from US markets. Chinese energy indices are dominated by state-owned large energy enterprises and growth-oriented new energy enterprises, with risk attributes fundamentally different from the AMEX Oil Index (XOI). This paper is the first to apply the portfolio hedging framework to Chinese energy indices, filling the gap in localized research.

Third, empirical gap: Insufficient quantitative analysis of the marginal contribution of crude oil futures. Existing portfolio hedging research mostly focuses on whether portfolio hedging outperforms single hedging, but lacks precise measurement of the incremental value of single futures instruments in the portfolio. This paper introduces the Marginal Contribution (MC) metric to quantify the efficiency improvement of crude oil futures based on existing stock index futures hedging, addressing the empirical question of "how useful are crude oil futures" and providing actionable decision-making references for investors in hedging instrument selection and weight allocation.

Fourth, heterogeneity gap: Differentiated hedging needs across energy indices of different scales have not been addressed. Existing research mostly focuses on single energy indices or single energy enterprises, without systematically comparing hedging effectiveness differences across different market capitalization scales. This paper simultaneously examines the CSI 300 Energy Index, CSI 500 Energy Index, and CSI 800 Energy Index, revealing the impact of scale heterogeneity on hedging effectiveness and providing differentiated strategy recommendations for different investor groups.

Based on the above literature, this paper constructs a portfolio hedging analytical framework combining stock index futures and crude oil futures, introduces marginal contribution analysis to quantify the incremental value of crude oil futures, explores the optimization of multi-futures portfolio hedging schemes, provides decision-making references for hedging for energy enterprises and investors, and offers empirical support for regulators to optimize futures market structure.

3. Model Framework

3.1. Portfolio Hedging

Portfolio hedging refers to the simultaneous use of two or more futures contracts during the hedging process to achieve more comprehensive and refined risk coverage of hedged assets. Its theoretical foundation stems from Modern Portfolio Theory (MPT), with the core idea of reducing overall portfolio risk through asset diversification. Under portfolio hedging, different futures contracts correspond to different risk sources, and by reasonably allocating the position ratios of each futures contract, multiple risk factors can be hedged simultaneously, thereby achieving better risk management results than hedging with a single futures contract.

Specifically, for energy index investors, the risks they face can be decomposed into two main components: one is the systematic risk of the stock market, referring to overall stock price fluctuations driven by factors such as macroeconomic conditions, monetary policy, and market sentiment; the other is the risk specific to energy commodities, referring to fluctuations specific to the energy industry driven by factors such as crude oil prices, supply-demand changes, and geopolitics. Stock index futures (such as CSI 300 Stock Index Futures IF and CSI 500 Stock Index Futures IC) mainly target the first type of risk, while crude oil futures (SC) mainly target the second type. Since the sources and transmission mechanisms of the two types of risks differ, their correlation structure is relatively stable and not completely positively correlated. Therefore, using stock index futures and crude oil futures simultaneously for portfolio hedging can utilize the risk diversification effect to reduce the overall variance of the hedging portfolio.

Let the spot return be $r_{s,t}$, the stock index futures return be $r_{f1,t}$, the crude oil futures return be $r_{f2,t}$, the hedging ratio vector be $h=\left[h_1,h_2\right]'$, Then the return on the hedging portfolio is:

$$r_{H,t} = r_{s,t} - h_1 r_{f1,t} - h_2 r_{f2,t}$$

The goal of minimum-variance hedging is to minimize $Var\left(r_{H,t}\right)$. When the correlation coefficient between two futures contracts is not 1, the minimum variance of portfolio hedging must be less than the minimum variance of any single futures contract. Under the OLS framework, the optimal hedging ratio is estimated using the following regression equation.

$$r_{s,t} = \alpha + h_1 r_{f1,t} + h_2 r_{f2,t} + \varepsilon_t$$

The specific hedging model for each energy index is explicitly specified as follows:

1) **CSI 300 Energy Index**: Hedged with CSI 300 Index Futures (IF) and crude oil futures (SC). The regression model is:

$$r_{300,t} = \alpha + h_{IF} r_{IF,t} + h_{SC} r_{SC,t} + \varepsilon_t$$

where $r_{300,t}$ is the return of the CSI 300 Energy Index, $r_{IF,t}$ is the return of IF futures, and $r_{SC,t}$ is the return of SC futures.

2) **CSI 500 Energy Index**: Hedged with CSI 500 Index Futures (IC) and crude oil futures (SC). The regression model is:

$$r_{500,t} = \alpha + h_{IC} r_{IC,t} + h_{SC} r_{SC,t} + \varepsilon_t$$

where $r_{500,t}$ is the return of the CSI 500 Energy Index, $r_{IC,t}$ is the return of IC futures, and $r_{SC,t}$ is the return of SC futures.

3) **CSI 800 Energy Index**: Hedged with CSI 300 Index Futures (IF), CSI 500 Index Futures (IC), and crude oil futures (SC). The regression model is:

$$r_{800,t} = \alpha + h_{IF} r_{IF,t} + h_{IC} r_{IC,t} + h_{SC} r_{SC,t} + \varepsilon_t$$

where $r_{800,t}$ is the return of the CSI 800 Energy Index. This three-futures portfolio simultaneously hedges the large-cap systematic risk (via IF), the mid-cap systematic risk (via IC), and the energy commodity-specific risk (via SC).

This paper selects OLS as the core estimation method, based on the following considerations: First, the OLS model is a classic implementation of the minimum-variance hedging framework, with advantages such as a solid theoretical foundation, simple computation, and strong interpretability of results; Second, relevant research shows that the OLS model has comparable hedging effectiveness to complex dynamic models (such as GARCH family) under certain market conditions, and is even superior to over-parameterized models; Third, compared to models such as VECM and GARCH, the OLS model has lower requirements for data length and distribution assumptions, making it more suitable for the research design of parallel comparison of three energy indices in this study. Fourth, this study uses the dynamic rolling window method, which to some extent compensates for the shortcomings of the OLS static assumption, enabling the hedging ratio to adjust with changes in market conditions.

3.2. Marginal Contribution Analysis

To quantify the incremental value of crude oil futures in portfolio hedging, this paper introduces the Marginal Contribution (MC) analysis framework. Lien and Tse (1998) propose the concept of "Incremental Hedging Effectiveness," providing a methodological foundation for evaluating multi-futures portfolio hedging performance. Building on this, Marginal Contribution is defined as the improvement in hedging efficiency after introducing crude oil futures on the basis of existing stock index futures hedging. Let $\mathrm{HE}_{\mathrm{single}}$ be the efficiency of hedging with a single stock index futures, $\mathrm{HE}_{\mathrm{combined}}$ be the efficiency of portfolio hedging, then the marginal contribution is:

$$\mathrm{MC} = \frac{\mathrm{HE}_{\mathrm{combined}} - \mathrm{HE}_{\mathrm{single}}}{\mathrm{HE}_{\mathrm{single}}}$$

Among them, Hedging Effectiveness (HE) is measured by the Variance Reduction Ratio (VRR):

$$\mathrm{HE} = \mathrm{VRR} = \frac{Var\left(r_{s,t}\right) - Var\left(r_{H,t}\right)}{Var\left(r_{s,t}\right)}$$

$\mathrm{MC} > 0$ indicates that crude oil futures play a positive incremental role in portfolio hedging; the larger the MC, the more significant the risk diversification contribution of crude oil futures. This framework not only answers the question of "whether crude oil futures are useful", but also provides a quantitative answer to "how useful", offering investors actionable decision-making basis for selecting hedging instruments and weight allocation.

3.3. Dynamic Rolling Window Method

To capture the time-varying characteristics of the hedging ratio and performance, this paper employs a dynamic rolling window approach. The estimation window is set to 250 trading days (approximately one year), and the prediction window is set to 20 trading days (approximately one month). The selection of rolling window parameters balances estimation precision with the responsiveness to market changes: 250 trading days approximately correspond to one year of sample data, enabling the capture of annual market structure changes while maintaining estimation stability; 20 trading days approximately correspond to one month of prediction horizon, aligning with the practical frequency of monthly hedging strategy review by investors. Within each estimation window, the OLS model is used to estimate the optimal hedging ratio, which is then applied to the subsequent prediction window to calculate the hedging portfolio returns. The window rolls forward by one prediction step, and the above process is repeated until the entire sample period is covered. This method can effectively reflect the impact of market environment changes on the hedging effectiveness, making the analysis results more realistic.

4. Empirical Data Explanation

4.1. Data Description

This paper selects the energy industry indices from China's A-share market as spot assets, including the CSI 300 Energy Index (000908.CSI), the CSI 500 Energy Index (H30250.CSI), and the CSI 800 Energy Index (000928.CSI). Futures contracts include the main contract of CSI 300 Index Futures (IF), the main contract of CSI 500 Index Futures (IC), and the main contract of crude oil futures (SC) on the Shanghai International Energy Exchange. The data are daily closing prices from March 26, 2018, to September 30, 2025. This starting point corresponds to the listing date of China's crude oil futures. All data are sourced from the Wind Financial Terminal.

The futures data used in this study are constructed as continuous main contracts to avoid price jumps during contract rollover. Specifically, for CSI 300 Index Futures (IF), CSI 500 Index Futures (IC), and crude oil futures (SC), the main contract is identified as the contract with the highest open interest on each trading day. When the dominant contract switches (typically at the end of the month approaching delivery), a rollover adjustment is applied. This study employs a backward adjustment method: upon rollover, the price difference between the new and old contracts on the rollover date is calculated and added to all historical prices of the new contract series. This ensures that the return series remains continuous and economically meaningful, eliminating artificial price gaps caused by contract switching while preserving the true return dynamics. The rollover is executed on the last trading day of the month preceding the delivery month, which is standard practice for Chinese commodity and index futures markets.

The daily return series for all spot indices and futures contracts are computed using the log-return formula:

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right)$$

where P_t denotes the closing price on day t. Log returns are preferred over simple returns due to their time-additivity property and better approximation of continuous compounding, which is standard in financial econometrics.

All spot and futures price series are synchronized by trading date. Since the CSI 300 Energy Index, CSI 500 Energy Index, and CSI 800 Energy Index are calculated only on trading days of the Shanghai Stock Exchange, while futures trade on both the China Financial Futures Exchange and the Shanghai International Energy Exchange, non-overlapping trading days are handled by excluding observations for which either the spot or any of the futures prices are missing. After synchronization, the sample retains only dates on which all series have valid observations. Within-series missing values are rare and occur only due to temporary data unavailability; these are addressed by linear interpolation if the gap is no more than two consecutive trading days, or by listwise deletion otherwise. The final synchronized sample spans from March 26, 2018, to September 30, 2025, ensuring consistency across all hedging models.

The constituent stocks of the CSI 300 Energy Index are composed of stocks belonging to the energy industry among the constituent stocks of the CSI 300 Index, mainly covering large energy enterprises with large market capitalization and good liquidity, dominated by traditional energy state-owned enterprises in petroleum, coal, and power sectors. The constituent stocks of the CSI 500 Energy Index are composed of stocks belonging to the energy industry among the constituent stocks of the CSI 500 Index, more representing medium-sized energy enterprises and covering multiple sub-sectors such as oil and gas exploration, coal, and new energy. The constituent stocks of the CSI 800 Energy Index are composed of stocks belonging to the energy industry among the constituent stocks of the CSI 800 Index (i.e., the union of the CSI 300 and CSI 500), providing comprehensive coverage of large and medium-sized energy stocks in the Class A Share market.

The above three futures instruments each have their own focus in terms of risk attributes: IF and IC correspond to the systematic risks of stock markets of different scales respectively, while SC targets the specific risks of energy commodities. The CSI 300 Index Futures, with the CSI 300 Index as its underlying, covers the 300 stocks with the largest market capitalization and best liquidity in the Class A Share market, and is mainly used for hedging the systematic risks of large-cap stock portfolios. The CSI 500 Index Futures, with the CSI 500 Index as its underlying, reflects the stock price performance of medium-cap companies and is more suitable for hedging the risk exposure of small and medium-cap stocks. Crude oil futures directly correspond to the prices of core commodity raw materials in the energy industry and can specifically hedge the specific industry risks of the energy index caused by fluctuations in crude oil prices.

4.2. Price Trend Analysis

Figure 1 shows the daily closing price trends of the CSI 300 Energy Index, IF Stock Index Futures, and SC Crude Oil Futures from March 2018 to September 2025.

The overall trends of the three are highly consistent, showing a pattern of initial fluctuations followed by an upward trend. At the beginning of 2020, there was a significant decline due to the impact of the pandemic, followed by a gradual recovery, with increased volatility after 2022. The price linkage between the energy index and stock index futures is relatively strong, providing a basis for hedging.

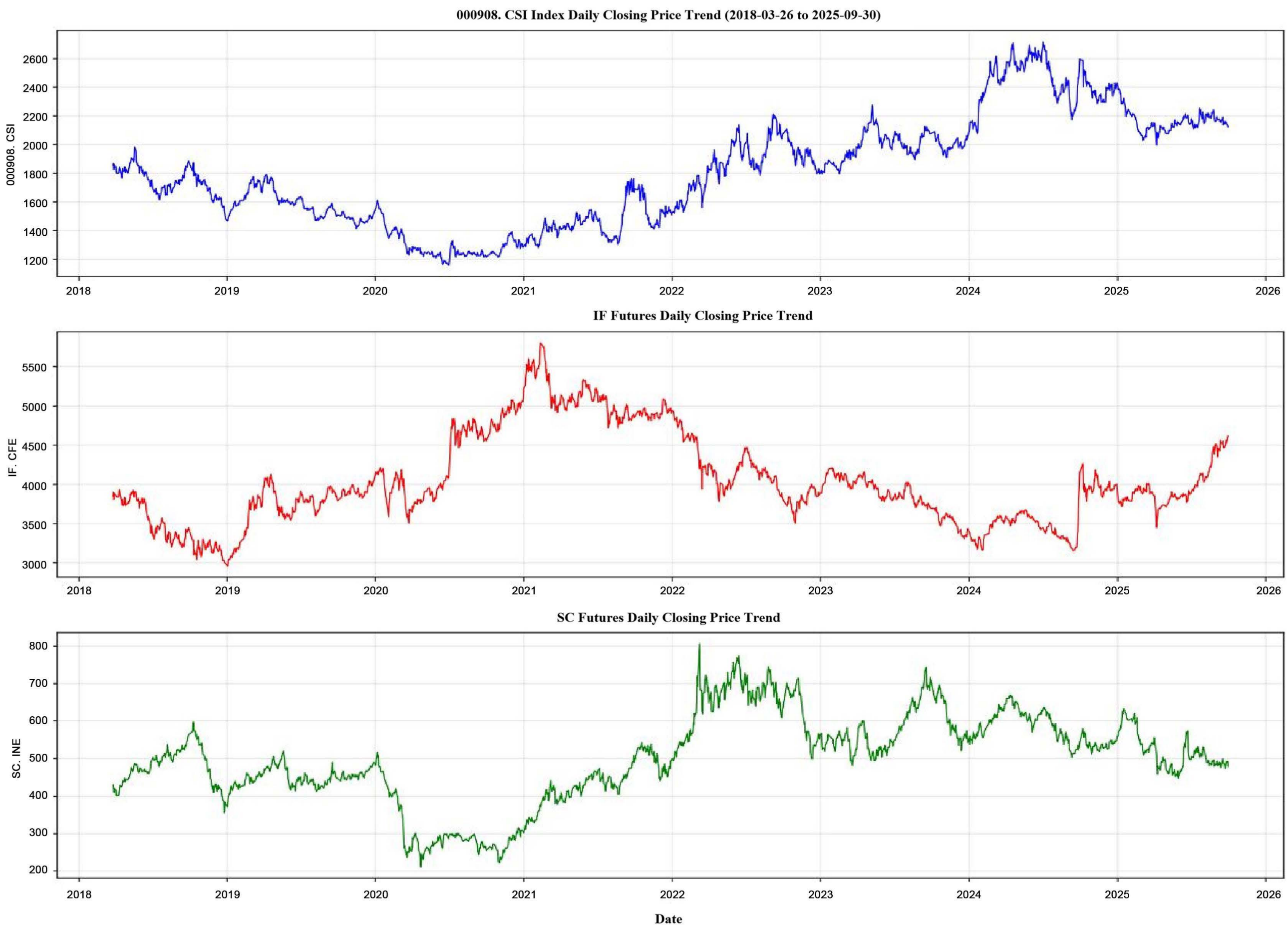

Figure 1. Closing price trends of 300 Energy, IF, and SC.

Figure 2 shows the price trends of the CSI 500 Energy Index and IC stock index futures. Compared with the 300 Energy Index, the 500 Energy Index has greater volatility, especially experiencing significant fluctuations in 2020 and 2022. The trend of IC futures is closer to that of the 500 Energy Index, reflecting that IC futures are more representative of energy stocks with small and medium market capitalizations.

Figure 3 shows the price trends of the CSI 800 Energy Index and IF, IC futures. The 800 Energy Index integrates the performance of large-, medium-, and small-cap energy stocks, with its trend falling between those of the 300 Energy and 500 Energy, and overall maintaining a high degree of correlation with stock index futures. The figure shows that the index and futures prices fluctuate in tandem during most periods, verifying the feasibility of hedging.

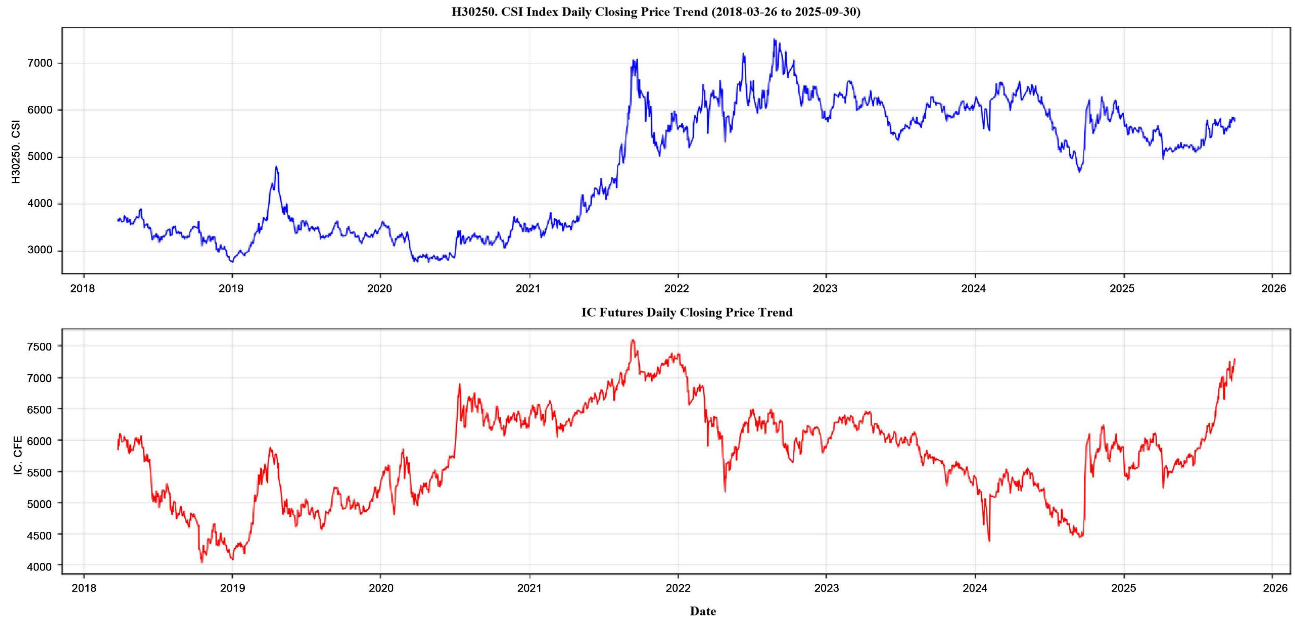

Figure 2. Closing price trends of 500 Energy and IC.

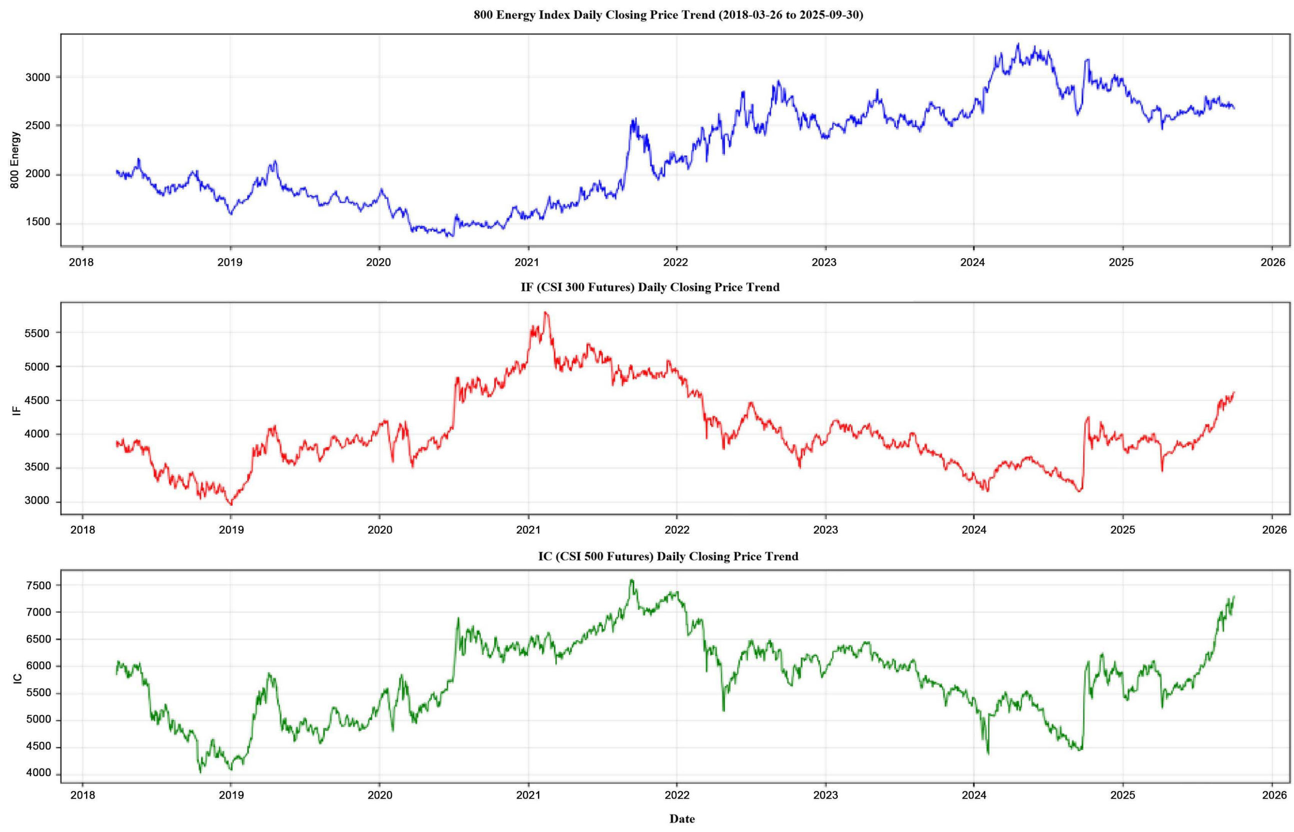

Figure 3. Closing price trends of 800 Energy, IF, and IC.

4.3. Descriptive Statistics

Before proceeding to regression-based hedge ratio estimation, this section presents descriptive statistics to validate the statistical properties of the data and justify the modeling choices. The descriptive statistics of daily log returns for the three energy indices and three futures contracts are summarized in Table 1. The statistics include mean, standard deviation, maximum, minimum, median and the number of returns. These metrics provide a preliminary understanding of the distributional characteristics of each series.

Table 1. Descriptive statistics results for returns.

Returns	Mean (%)	Std.Dev (%)	Maximum (%)	Minimum (%)	Median (%)	Number
300 Energy	0.0073	1.5281	6.6323	−8.0741	−0.0033	1827
500 Energy	0.0251	1.8162	8.3391	−9.5545	−0.0012	1827
800 Energy	0.0151	1.5584	6.1694	−8.0523	0.0295	1827
IF	0.0099	1.3216	8.3369	−10.6357	−0.0255	1827
IC	0.0121	1.4720	9.6264	−10.6683	0.0096	1827
SC	0.0060	2.2948	10.1111	−14.1319	0.0880	1827

5. Empirical Results and Analysis

5.1. Dynamic Hedging Ratios

This paper employs the dynamic rolling window method to estimate the hedging ratios. The estimation window is set to 250 trading days, the prediction window to 20 trading days, and the rolling step to 20 trading days. Within each estimation window, the OLS model is used to estimate the optimal hedging ratio, which is then applied to the subsequent prediction window to calculate the hedging portfolio return. The window rolls forward by one prediction step, and the above process is repeated until the entire sample period is covered.

Figure 4 shows the trend of the hedging ratio over time estimated using a rolling window for the CSI 300 Energy Index with IF futures, SC futures, and their combination (Multi). Overall, the hedging ratio of IF futures remains between 0.4 and 0.8, while that of SC futures fluctuates around 0.2 to 0.4, and the hedging ratio of IF futures in the combined hedge is relatively high. During the early stage of the COVID-19 pandemic in 2020 and the Russia-Ukraine conflict in 2022, all hedging ratios exhibit structural changes, reflecting the impact of market extreme events on optimal hedging ratios.

Figure 5 reflects the dynamic hedging ratios of each futures instrument under single-futures hedging and portfolio-futures hedging for the CSI 500 Energy Index. The hedging ratio of IC futures stabilizes between 0.5 and 1.2, the ratio of SC futures fluctuates around 0.1 to 0.4, and IC futures dominate in portfolio hedging. The hedging ratio fluctuations of the 500 Energy Index are greater than those of the 300 Energy Index, consistent with the higher volatility characteristics of the CSI 500 Energy Index constituent stocks dominated by small and medium-cap enterprises.

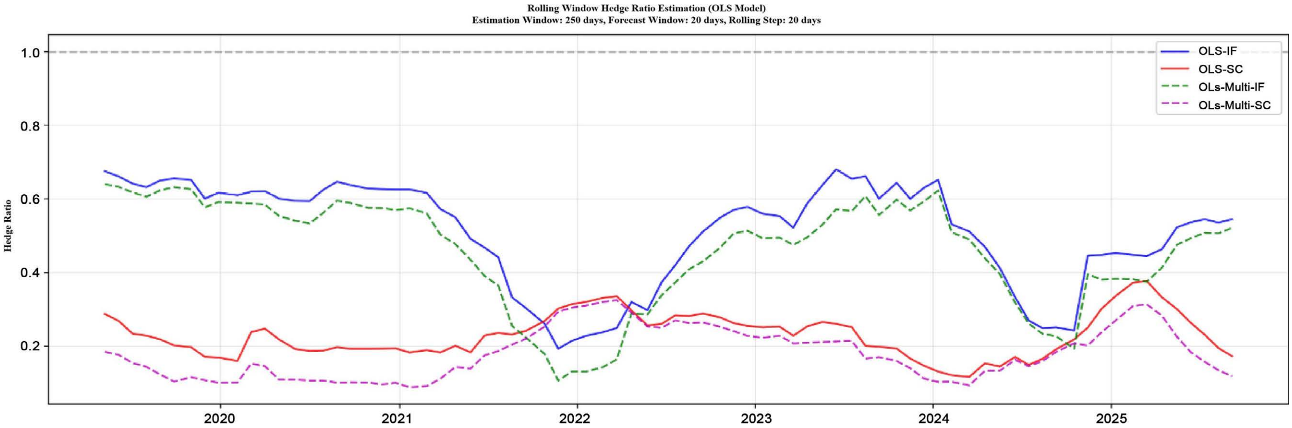

Figure 4. Dynamic hedging ratio of CSI 300 Energy.

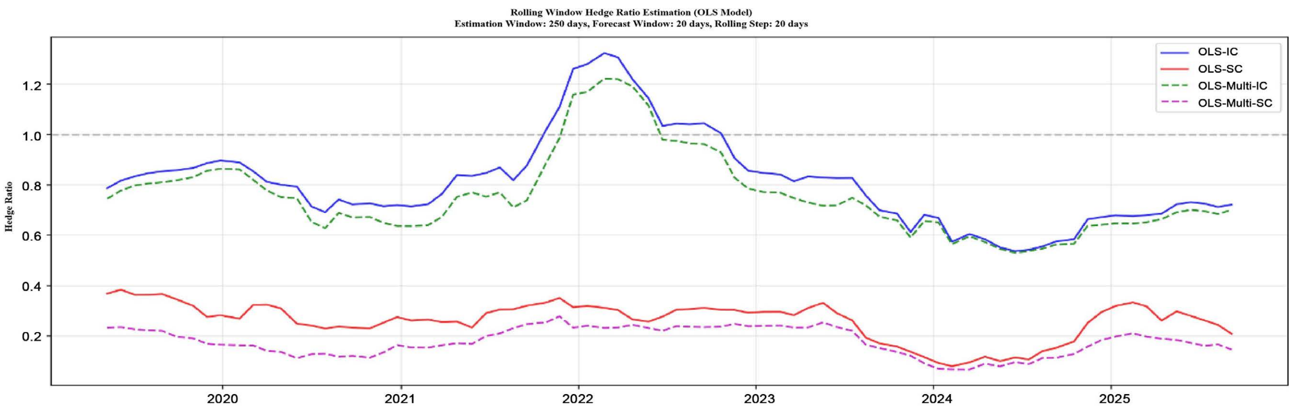

Figure 5. Dynamic hedging ratio of CSI 500 Energy.

Figure 6 shows the changes in the hedging ratios of IF, IC, and SC under single-futures hedging for the CSI 800 Energy Index. The hedging ratios of IF and IC futures fluctuate around 0.4 and 0.6 respectively, while the ratio of SC futures remains at a relatively low level. The 800 Energy Index integrates the performance of large-, medium-, and small-cap energy stocks, with its hedging ratio trends falling between those of the 300 Energy and 500 Energy indices.

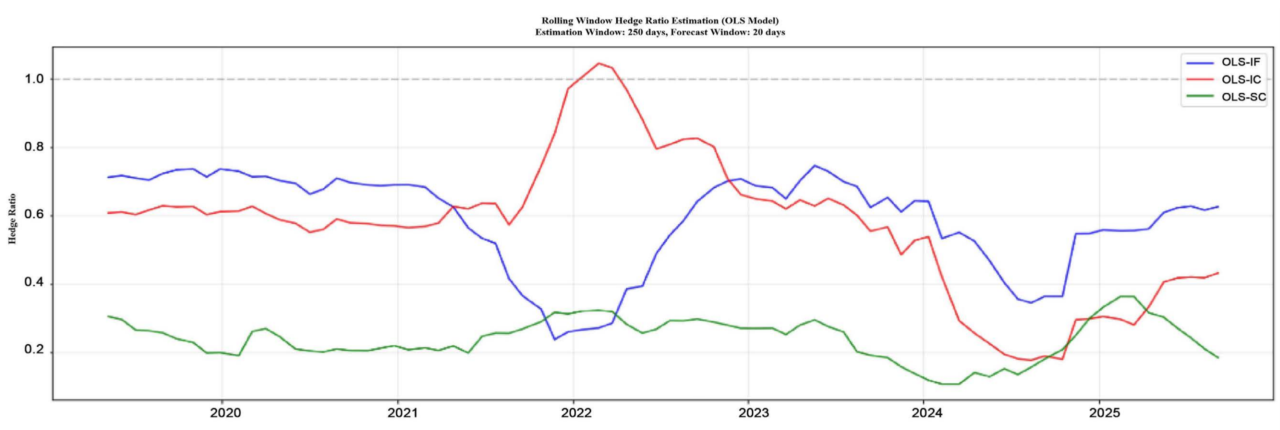

Figure 6. Dynamic hedging ratio of CSI 800 Energy.

5.2. Dynamic Hedging Performance

Similarly, this paper calculates the hedging performance VRR for each prediction window. Figure 7 shows the time-varying variance reduction rate (VRR) of different hedging schemes for the CSI 300 Energy Index. The VRR of IF futures and portfolio hedging basically remains between 0.1 and 0.3, while the VRR of SC futures fluctuates significantly and is negative in some periods. Negative VRR implies that hedging increases rather than reduces risk, which typically occurs when the covariance between crude oil and the energy index is negative or when the basis fluctuates significantly, indicating that single crude oil futures in some market states not only fail to hedge risk but also amplify it.

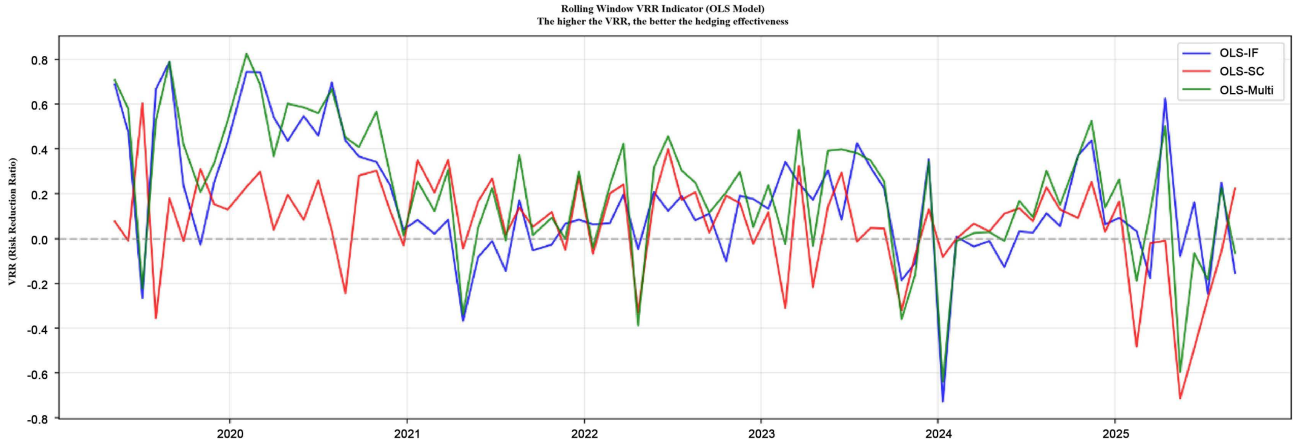

Figure 7. Dynamic hedging performance of CSI 300 Energy.

Figure 8 shows the VRR dynamics of the CSI 500 Energy Index under different hedging schemes. The VRR of IC futures and portfolio hedging performs excellently, with the VRR of portfolio hedging above 0.3 in most periods and approaching 0.5 in some periods. The VRR of SC futures is generally low and negative in some periods. The overall hedging performance of the 500 Energy Index outperforms the 300 Energy Index, which may be related to the fact that the constituent stocks of the 500 Energy Index are mainly small and medium-cap enterprises, whose correlation structure with the underlying index of stock index futures is more conducive to hedging.

Figure 9 shows the VRR changes of the CSI 800 Energy Index. The VRR of portfolio hedging is stable between 0.2 and 0.4, outperforming single-futures hedging. The performance of the 800 Energy Index falls between the 300 Energy and 500 Energy indices, reflecting the comprehensive characteristics of its constituent stock structure.

5.3. Comparative Analysis of Hedging Performance

Based on the VRR presented in the above figures, Table 2 shows the mean and standard deviation of VRR for three energy indices under single futures hedging and portfolio futures hedging scenarios, as well as VRR statistical significance test results. For the CSI 800 Energy Index, the "Multi" (portfolio) hedging strategy refers to the simultaneous use of CSI 300 Index Futures (IF), CSI 500 Index Futures (IC), and crude oil futures (SC) within a three-futures portfolio framework. This three-futures specification is necessary because the CSI 800 Energy Index comprises both large-cap and mid-cap energy stocks, requiring both IF and IC to comprehensively hedge stock market systematic risk.

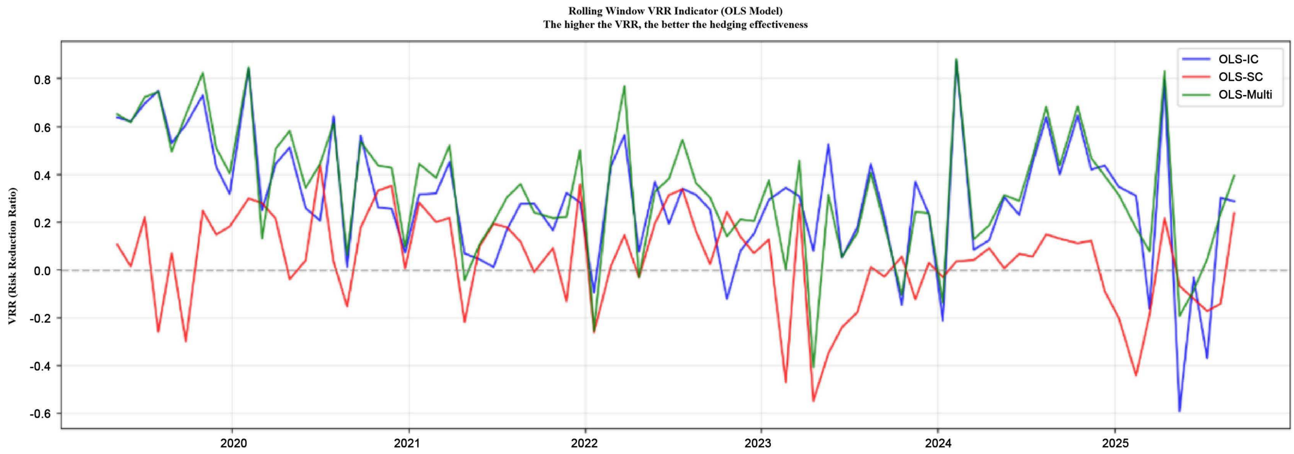

Figure 8. Dynamic hedging performance of CSI 500 Energy.

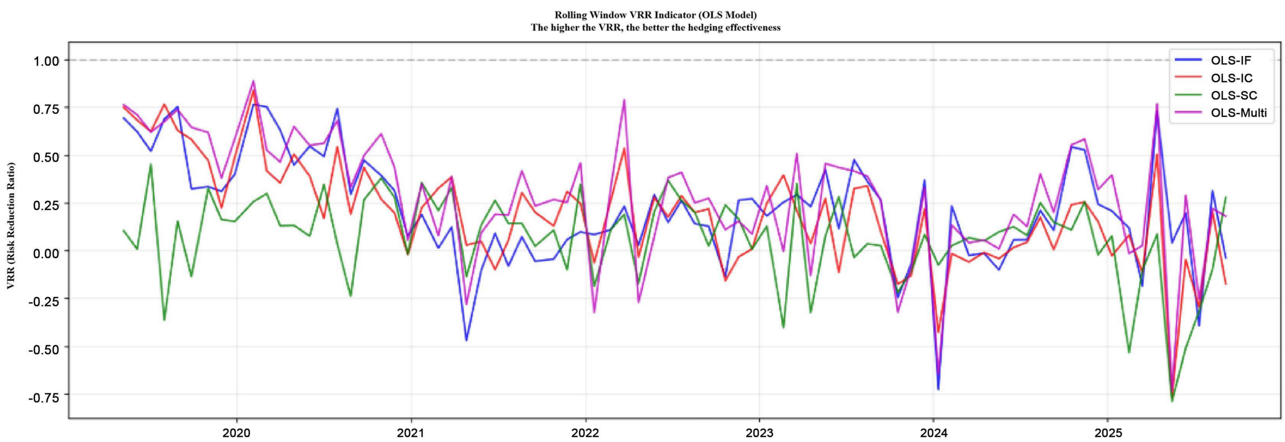

Figure 9. Dynamic hedging performance of CSI 800 Energy.

VRR t-tests indicate that, except for some cases of SC futures, the mean VRR of most hedging schemes is significantly greater than zero at the 5% significance level, indicating that hedging strategies have statistically significant risk reduction effects. Paired t-tests for the difference between portfolio and single stock index futures hedging VRR show that portfolio hedging significantly outperforms single stock index futures hedging (significance level of 5% for 300 Energy and 800 Energy, and 10% for 500 Energy).

The results in the table demonstrate the following characteristics of the hedging performance of the three energy indices:

Table 2. VRR statistics of different hedging schemes.

Index		Single Futures Hedging			Portfolio Hedging	VRR Difference Test (Portfolio vs. Single Stock Index)
		IF	IC	SC	Multi	
300 Energy	Mean	0.1659	—	0.0698	**0.2171**	**0.0512****
	Std. Dev.	0.2764	—	0.2180	0.2982	**(2.34)**
500 Energy	Mean	—	0.2959	0.0450	**0.3337**	**0.0378***
	Std. Dev.	—	0.2708	0.2029	**0.2675**	**(1.87)**
800 Energy	Mean	0.2200	0.1908	0.0673	**0.2877**	**0.0677****
	Std. Dev.	0.2874	0.2763	0.2298	0.3190	**(2.15)**

Note: The numbers in parentheses represent t-values. *, ** indicate significance at the 10% and 5% levels, respectively. For the CSI 800 Energy Index, the "Multi" (portfolio) hedging strategy refers to the simultaneous use of CSI 300 Index Futures (IF), CSI 500 Index Futures (IC), and crude oil futures (SC) within a three-futures portfolio framework. The VRR difference test (0.0677) is the difference between Portfolio Hedging (0.2877) and the maximum Single Stock Index Futures Hedging (0.2200).

1) The average hedging performance of IF and IC stock index futures ranges between 16.59% and 29.59%, which is relatively reasonable. The constituent stocks of energy indices only include energy industry stocks, differing from broad-based indices such as CSI 300, CSI 500, and CSI 800. The hedging performance is relatively low but within a reasonable range.

2) The average hedging performance of SC crude oil futures ranges between 4.50% and 6.98%, lower than that of stock index futures, indicating that the risks of the energy industry index mainly stem from the systematic risks of the stock market, while only a small portion comes from crude oil price fluctuations. Notably, the standard deviation of SC futures VRR is relatively large, and VRR is negative in some periods, indicating that the hedging effect of single crude oil futures is unstable and may increase risk rather than reduce it in certain market states.

3) The performance of portfolio hedging is higher than that of single stock index futures hedging, and also much higher than that of single crude oil futures hedging. The mean VRR of portfolio hedging for the three energy indices is 21.71% (300 Energy), 33.37% (500 Energy), and 28.77% (800 Energy), respectively, significantly outperforming single stock index futures hedging (paired t-test significant). This reflects the advantage of portfolio hedging over single futures hedging, and verifies H1. Both stock index futures and crude oil futures exhibit strong marginal contributions.

4) Among the three energy indices, the single-IC hedging performance of the 500 Energy Index reached 29.59%, and the portfolio hedging performance reached 33.37%, higher than those of the 300 Energy Index and the 800 Energy Index. This may be related to the fact that the constituent stocks of the 500 Energy Index are mainly small- and medium-cap energy enterprises, which have a higher correlation with the underlying index of CSI 500 Index Futures. The hedging perfor-

mance of the 300 Energy Index is relatively weak, possibly because the constituent stocks of the 300 Energy Index are mainly large state-owned energy enterprises, whose stock price fluctuations are less affected by systematic factors, resulting in relatively low hedging demand.

5.4. Marginal Contribution Analysis Results

Based on the hedging performance of stock index futures, this section analyzes the marginal contribution of crude oil futures to the hedging of energy indices by comparing the portfolio hedging performance with that of stock index futures. The relevant results are shown in Table 3.

Table 3. Marginal contribution of crude oil futures.

Index	Stock Index Futures Hedging	Combined Hedging	Marginal Contribution
300 Energy	0.1659	**0.2171**	30.86%
500 Energy	0.2959	**0.3337**	12.77%
800 Energy	0.2200	**0.2877**	30.77%

Note: The single-futures benchmark for CSI 800 Energy is the IF futures (HE = 0.2200), which yields the highest single-futures hedging effectiveness between IF and IC for this index. Using the best-performing single futures as the baseline provides a conservative estimate of the incremental value added by crude oil futures in the portfolio.

The results in the table above show that the hedging effect of the futures portfolio is significantly better than that of single-futures hedging, verifying H1. This result validates the core hypothesis of this paper: using stock index futures and crude oil futures simultaneously for portfolio hedging can more comprehensively hedge the systematic risks and commodity risks faced by the energy industry. The marginal contribution of crude oil futures is 30.86% in 300 Energy, 30.77% in 800 Energy, and 12.77% in 500 Energy. This indicates that large-cap stocks in the energy industry are more affected by the risk of crude oil price fluctuations, and using crude oil futures for combined hedging can better avoid systematic risks. Furthermore, the superiority of portfolio hedging stems from the risk diversification effect. Stock index futures mainly hedge the systematic risks of the stock market, while crude oil futures mainly hedge the price risks of energy commodities. Since the sources and transmission mechanisms of the two types of risks are different, single-futures cannot fully cover all the risk exposures of the energy industry. Portfolio hedging achieves a more comprehensive risk management effect by simultaneously hedging both types of risks.

6. Research Conclusion

This paper takes the CSI 300 Energy Index, CSI 500 Energy Index, and CSI 800 Energy Index as research objects, systematically exploring the effectiveness differences of portfolio hedging strategies combining stock index futures and crude oil futures, as well as the marginal contribution of crude oil futures. The main research conclusions are as follows:

First, the performance of portfolio hedging is higher than that of single stock index futures hedging and far higher than that of single crude oil futures hedging. This conclusion supports the effectiveness of portfolio hedging strategies in risk management of energy industry index investment and verifies H1 that more comprehensive risk management effects can be achieved by simultaneously hedging the systematic risk of the stock market and the specific risk of energy commodities. The mean VRR of portfolio hedging for the three energy indices is 21.71%, 33.37%, and 28.77%, respectively, significantly outperforming single stock index futures hedging (paired t-test significant). Secondly, for the hedging of energy indices, the performance of stock index futures hedging is higher than that of crude oil futures hedging. This indicates that most of the risks of energy industry stocks come from the stock market, with only a small portion coming from crude oil price fluctuations. The mean VRR of SC futures is only 4.50% - 6.98%, and VRR is negative in some periods, indicating that the hedging effect of single crude oil futures is unstable and may increase risk rather than reduce it in certain market states. Thirdly, crude oil futures have made a significant positive marginal contribution to portfolio hedging, verifying H2. The MC values of all three energy indices are positive, with the 300 Energy Index having the highest marginal contribution (MC = 30.86%), followed by the 800 Energy Index (MC = 30.77%), and the 500 Energy Index having the lowest (MC = 12.77%). This shows that crude oil futures are not only a direct tool for hedging energy commodity risks but also an important supplement for optimizing the risk structure of the hedging portfolio. When investors hedge energy industry indices, they should include crude oil futures in the hedging instrument portfolio to enhance the overall risk management effect. However, it is important to note that MC measures the efficiency improvement, not the absolute VRR increment, and both should be considered in actual decision-making. Fourth, dynamic hedging analysis indicates that portfolio hedging generally maintains a relatively stable VRR level over the sample period, while the effectiveness of single-futures hedging is significantly affected by market states. Dynamic analysis based on a 250-day rolling window shows that in most market environments, portfolio hedging can maintain positive VRR, while single-futures hedging (especially SC futures) exhibits negative VRR in some periods. This finding provides empirical support for investors to implement continuous hedging strategies in complex and volatile market environments, partially verifying H3.

Based on the above conclusions, this paper proposes the following policy recommendations: For energy enterprise investors: Large and medium-sized energy enterprises (corresponding to CSI 300 Energy Index constituent stocks) should fully recognize the marginal contribution of crude oil futures when conducting risk management. This paper finds that in the portfolio hedging of the 300 Energy Index, the marginal contribution of crude oil futures is as high as 30.86%, meaning that introducing crude oil futures on the basis of existing stock index futures hedging can improve hedging efficiency by nearly one-third. Investors should include crude oil futures in the hedging instrument portfolio to achieve more comprehensive risk coverage. For small and medium-cap energy enterprise investors (corresponding to the CSI 500 Energy Index), the hedging effect of stock index futures is already relatively ideal (VRR = 29.59%), and the marginal contribution of crude oil futures is relatively low (12.77%). Investors may decide whether to introduce crude oil futures based on actual cost-benefit trade-offs. For energy industry index fund managers: Institutions managing energy industry index funds should establish dynamic portfolio hedging mechanisms. The rolling window analysis in this paper indicates that optimal hedge ratios change with market conditions, and fund managers should regularly (e.g., monthly) review and adjust hedge ratios rather than adopting fixed ratios. Simultaneously, emergency plans should be established for extreme market states, promptly adjusting hedging instrument weights or suspending the use of specific instruments when single futures exhibit negative VRR. For regulatory authorities: The crude oil futures of the Shanghai International Energy Exchange (INE) have basic price discovery and risk transfer functions, but their hedging effectiveness (especially in single-futures hedging) remains unstable. It is recommended that regulatory authorities further improve the market maker mechanism for crude oil futures, enhance market liquidity and depth, reduce basis volatility, and thereby strengthen the hedging function of crude oil futures. Additionally, the introduction of more energy derivatives (such as natural gas futures and carbon emission rights futures) could be considered to enrich energy industry risk management instruments and provide investors with more comprehensive risk hedging means. Furthermore, risk education for energy industry investors should be strengthened, promoting the concept of portfolio hedging to prevent excessive reliance on single futures instruments.

Despite the relatively clear conclusions reached in this paper, the following research limitations remain, awaiting improvement in future studies. First, this study primarily employs the OLS model for hedge ratio estimation. Although the rolling window method partially compensates for the static assumption, dynamic models such as GARCH family, DCC, and BEKK are not systematically introduced in the main analysis. Future research could introduce more complex dynamic models such as DCC-GARCH, ADCC-GARCH, and Copula-GARCH for more comprehensive methodological comparisons. Second, this study does not incorporate transaction costs, including trading fees, bid-ask spreads (slippage), and contract rollover costs during main contract switching. The primary reason for this omission is that the hedging effectiveness metric employed in this study is the Variance Reduction Ratio (VRR), which measures the proportional reduction in portfolio return variance achieved by hedging. VRR is a risk-centric metric that depends on the covariance structure between spot and futures returns, rather than on the absolute level of returns. Transaction costs, by contrast, primarily affect the net profitability (return) of hedging strategies rather than their variance-reduction capability. Therefore, the exclusion of transaction costs does not materially bias the

VRR-based assessment of hedging effectiveness. Nevertheless, in practical implementation, transaction costs are non-negligible: crude oil futures transaction fees, margin requirements (typically 10% - 15%), and rollover costs during main contract switching all affect the net performance of hedging portfolios. Future research could incorporate these cost factors to calculate net hedging performance and conduct cost-benefit analyses, thereby making strategies more practically applicable.

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Author Contributions

Conceptualization, C.L.; methodology, H.Y.; software, H.Y.; validation, C.L. and H.Y.; formal analysis, C.L.; investigation, H.Y.; resources, C.L.; data curation, H.Y.; writing—original draft preparation, H.Y.; writing—review and editing, C.L. and H.Y.; visualization, H.Y.; supervision, C.L.; project administration, C.L.; funding acquisition, C.L. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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