The Impact of the Fed's Interest Rate Adjustment Cycle on the Price of WTI Crude Oil Futures

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Abstract. This article is based on monthly data from January 2016 to January 2022, including the US Federal Funds Rate and WTI crude oil futures price index. A TVP-VAR model is constructed to study the impact of the Federal Reserve's interest rate cycles on WTI crude oil futures prices. The research found a positive correlation between crude oil futures prices and the Federal Reserve's interest rate cycles. That means that when the Federal Reserve raises or lowers the US Federal Funds Rate, it leads to an increase or decrease in crude oil futures prices. Therefore, it is believed that in the current context of global quantitative easing and the sustained rise in international crude oil prices, China should formulate a new energy strategy that matches the high-quality development of the social economy and accelerate the transformation and upgrading of the crude oil industry.

Keywords: WTI crude oil futures price; Federal Reserve interest rate hike; TVP-VAR model; impulse response.

1. Literature Review

In the early literature, most scholars focused on the study of fundamental factors. Chinese scholars Li Zhuo and Zhang Qian (2012) used the symbol-constrained VAR model to distinguish the speculative shock in the oil futures market from the basic supply and demand shock in the oil market, and found that the demand shock of economic activities ranged from 30% to 50%, and the supply shock would lead to 30% short-term fluctuation of oil price, but its impact would quickly fade.[1] Aastveit K.A. (2013) conducted a study using data from 1974 to 2008 and found that the persistence of oil price rise caused by demand shock was more obvious when the factor augmentation-VAR model was used.[2] Tan Xiaofen et al. (2015) used the TVP-FAVAR model to study the main driving factors of the evolution of international crude oil prices during 2000-2015 and found that the increase of crude oil supply and demand pressure was the main reason for the rise of oil prices during 2000-2008; The sharp decline in international crude oil prices in the second half of 2014 is the result of the sharp increase in global oil supply and the gradual appreciation of the US dollar exchange rate. Chinese demand is not the main factor affecting the volatility of international oil prices, but the impact of Chinese demand on oil prices is gradually increasing.[3]

With the improvement of crude oil futures market, some scholars have studied the speculative factors. Han Liyan and Yin Libo (2012) took speculative factors as proxy variables and selected the proportion of non-commercial positions in futures contracts to conduct relevant research, pointing out that the driving force of long-term rise in commodity prices is still the real economy factor, international speculative factors will push up commodity prices in the short term, and the impact of China factors on commodity prices is indirect and can be ignored.[4] Sui Yanxiu and Guo Qiang (2014) found in their empirical study based on structural breakpoint test that there are obvious long-term and short-term speculative activities in the oil futures market, among which long-term speculative factors have a deeper impact on oil price fluctuations.[5] Tian Lihui and Tan Dekai (2014) analyzed the influencing factors of international crude oil price fluctuations from 2002 to 2012, and believed that the main reason for the continuous rise of international crude oil prices since 2002 was market financial speculation, which played a leading and amplifying role in the international crude oil market price fluctuations in 2008.[6] Li Zhuo and Li Hai (2017) empirically analyzed the immediate causal relationship between international crude oil price fluctuations and various influencing factors from the perspective of commodity finance, and found that the investment

decision of index investors is determined by the price trend of the entire market, and the influencing factors of price trend should not be ignored when making long-term investment decisions.[7]

At present, many scholars believe that financial factors are an important reason for the change of international crude oil prices. Li Zhiguo (2012) empirically studied the relationship between US crude oil spot price and US dollar index from January 2000 to April 2001 by using Granger causality test and ECM model, and the results showed that the change of US dollar index was the Granger cause of the change of WTI crude oil spot price. However, the change of WTI crude oil spot price is not the Granger reason for the change of the US dollar index. Cheng Minghua (2013) believed that the frequent and violent fluctuations of international crude oil prices from 2000 to 2012 were the result of a variety of financial factors such as the US dollar exchange rate and speculative factors. [8] Tian Lihui and Tan Dekai (2015) utilized the ARDL and VAR models to examine the main factors influencing international crude oil price changes from 2002 to 2012. They found that China's crude oil demand did not play a significant role in the long-term trend of international crude oil prices, which were largely affected by financial factors. In the short term, Chinese petroleum demand factors influenced oil prices but had a weaker impact compared to financial factors.[9] Han Liyan et al. (2017), after conducting research using VAR and other econometric models, found that global GDP and total international trade have a significant positive impact on international oil prices and are long-term related to them, while the influence of the US dollar index on oil price fluctuations is apparent in the short term but exhibits a two-month lag effect.[10] Ding Lei and Guo Wanshan (2018) argued that there is a long-term equilibrium relationship between Chinese inflation, RMB exchange rate against the US dollar, and international oil prices. Once the exchange rate and international oil prices are affected, it will be transmitted to China domestically, resulting in increased domestic inflation rates.[11]

2. Research Data and Method

2.1. Data Source and Variable Selection

There are contracts available for trading in WTI crude oil futures every month, but the price of each contract is not consistent, and the amount of holdings is also different, the author believes that it is more reasonable to index the price of crude oil futures. This paper selects the monthly data of WTI crude oil futures price index provided by Chinese financial derivatives trading information system, which is an important reference for domestic crude oil derivatives trading. The WTI crude oil futures price index is calculated by weighting the price of each month's contract of light crude oil varieties listed on the New York Mercantile Exchange. Compared with the one-month contract, it is more comprehensive and can better reflect the price level of crude oil futures at that time. The Fed will not directly adjust the deposit or loan interest rate, but adjust the US federal funds rate, which can quickly and truly reflect the surplus and shortage of funds of US commercial banks. Interest rate adjustment is the monetary means of the Federal Reserve to solve the inflation in the United States, so the US Federal funds rate is chosen to represent the cycle interest rate of the Federal Reserve to raise or lower interest rates. The monthly data of interest rates are from the WIND database. WTI crude oil futures prices have seen two lows in recent years, the first in January 2016 and the second in April 2020. This paper takes January 2016 as the starting point of data samples, and selects January 2016 - April 2022 as the sample interval. The sample interval includes two rising stages and one falling stage. The two rising stages are January 2016 - October 2018 and April 2020 - April 2022. One decline period is from October 2018 to April 2020.

The names, abbreviations and meanings of the variables involved in the study are shown in Table 1. In order to reduce the degree of heteroscedasticity of the crude oil futures price sample data, the crude oil futures price data are treated logarithmically.

Table 1. Variables, Symbols and Meanings

Variables	Symbols	Meanings
Crude oil futures price index	LNPF	WTI crude oil futures price index month-end settlement price, logarithm has been taken
Us federal funds rate	FFR	Fed rate hike or rate cut month end statistics

2.2. Descriptive Statistics of Variables

After selecting variables, this paper draws the trend chart of the crude oil futures price index and the US federal funds rate (see Figure 2.1). As can be seen from Figure 2.1, from January 2016 to October 2018, the crude oil futures price rose from $34.4 to $70.65, with a volatility of 105.38%. The calculation process of the volatility is shown in Equation (1). From October 2018 to April 2020, the crude oil futures price fell from $70.65 to $26.31, with a volatility of 168.56%; From April 2020 to April 2022, the crude oil futures price rose from $26.31 to $96.93, with a volatility of 268.45%, and the current oil price has exceeded the maximum value in October 2018. In the selected sample interval, the price of crude oil futures fluctuates quite sharply.

$$\text{Volatility} = (\text{high price} - \text{low price})/\text{low price} \times 100\% \quad (1)$$

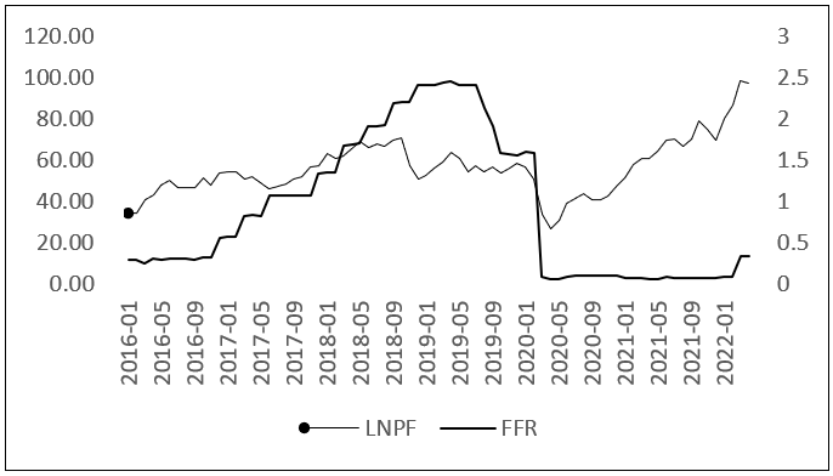


Fig 1. LNPF and FFR trends from January 2016 to April 2022

According to the change trends of LNPF and FFR in Figure 1, from January 2016 to October 2018, crude oil futures prices and the US federal funds rate showed a common upward trend; From October 2018 to April 2020, crude oil futures prices and the US federal funds rate showed a common downward trend. Both crude oil futures prices and the US federal funds rate fell to a trough in April 2020, which may be related to the sudden outbreak of the novel coronavirus pneumonia in early 2020, the overall international energy consumption market malaise, and the international shutdown and production. The Federal Reserve has continued to implement a low interest rate policy since March 2020. If the Federal Reserve does not raise interest rates, international crude oil futures prices and the U.S. inflation rate will continue to rise.

Through the preliminary analysis of the trend of variables, it can be seen that there is a certain same trend between the trend of international crude oil futures price index and the trend of federal funds rate of the United States, that is, there may be correlation between variables. Therefore, this paper constructs a time-varying parameter vector autoregressive (TVP-VAR) model to empirically analyze the time-varying influence of the US Federal funds rate FFR on the crude oil futures price index LNPF, and examines the positive effect of FFR.

2.3. Introduction to Empirical Research Methods

When analyzing the relationship between FFR of the US Federal Funds rate and LNPF of the crude oil futures price index, in order to ensure the true and effective regression results, first of all, ADF

was used to test whether the original time series of variables LNPF and FFR were stable. If the original time series of variables LNPF and FFR were stable, the TVP-VAR model could be established. If the original time series of the variables LNPF and FFR is non-stationary, the variables LNPF and FFR should be differentially treated, and then the stationarity of the difference series should be tested. If the stationary sequence is obtained after the first difference is adopted, the TVP-VAR model can be established and the dynamic balance relationship of endogenous variables can be empirically analyzed by using the model. Secondly, MCMC algorithm is used to extract samples to support the posterior judgment of TVP-VAR model. Then, the equally spaced impulse response and time-point impulse response were constructed successively to comprehensively understand the influence of the independent variable of the Federal funds rate FFR on the dependent variable of the crude oil futures price index LNPF.

The TVP-VAR model loosens the constant constraint of parameters on the traditional SVAR model and introduces time-varying features, which are time-varying and nonlinear. According to Nakajima et al. (2011), a TVP-VAR model expression form is established:

$$\begin{aligned} y_t &= X_t\beta_t + A_t^{-1}\sum_t \varepsilon_t \\ t &= s+1,\ldots,n \\ \varepsilon_t &\sim N(0, I_k) \end{aligned} \tag{2}$$

Where y_t is the $K\times1$ vector in the observed variable, and A_t is the parameter matrix that changes with time. According to Primiceri (2005), the parameters in equation (1) are assumed to follow the following random walk process:

$$\begin{aligned} \beta_{t+1} &= \beta_t + \mu_{\beta t} \\ a_{t+1} &= a_t + \mu_{at} \\ h_{t+1} &= h_t + \mu_{ht} \end{aligned} \begin{pmatrix} \varepsilon_t \\ \mu_{\beta t} \\ \mu_{at} \\ \mu_{ht} \end{pmatrix} \sim N(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_\alpha & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix}) \tag{3}$$

Among them, $t=s+1,\ldots,n, \beta_{s+1}\sim N(\mu_{\beta0}, \sum_{\beta0}), \alpha_{s+1}\sim N(\mu_{\alpha0}, \sum_{\alpha0}), h_{s+1}\sim N(\mu_{h0}, \sum_{h0})$. Bayesian method is used for model estimation, and MCMC (Markov Chain Monte Carlo) method is used to complete the posterior value estimation of parameters.

3. Empirical Analysis

3.1. Stationarity Test of Time Series

In order to avoid the correlation between the US Federal Funds rate FFR and the crude oil futures price index LNPF without causality, this paper proposes a null hypothesis before the stationarity test: there is a unit root in the time series of variables. When the P value in the test result is less than 0.05, the null hypothesis is not accepted, which indicates that the time series of the variable has stationarity. When the P-value is greater than 0.05, the null hypothesis is accepted, indicating that the time series is non-stationary. First, the original time series of the variables LNPF and FFR are tested (the results are shown in Table 2). Table 2 shows that the two variables are non-stationary time series. In this paper, the first difference of variables LNPF and FFR is carried out, and then the time series after LNPF and FFR are tested. Among them, test type C means that the test equation contains intercept term, test type T means that the test equation contains trend term, test type K means that the test equation contains lag term, and N means that there is neither intercept term nor time trend term in the test variance.

Table 2. Results of the Augmented Dickey-Fuller (ADF) Test

Time	Variable name	Test type (C,T,K)	Critical values	T-value	P-value
2016-2022	LNPF	(C,1)	-4.087***	-1.749	0.7191
	D(LNPF)	(N,0)	-2.597***	-6.398	0.0000
	FFR	(N,0)	-2.596***	-0.691	0.4144
	D(FFR)	(N,0)	-2.597***	-7.928	0.0000

Note: ***, ** and * denote significance at the 1%, 5%, and 10% levels, respectively.

The results of the Augmented Dickey-Fuller (ADF) tests for WTI crude oil futures price index (LNPF) and the US Federal Funds Rate (FFR) indicate that the original series of both variables were non-stationary from January 2016 to April 2022. However, the first-differenced series of both variables exhibited stationarity. Therefore, a TVP-VAR model was constructed using the time series of LNPF and FFR after applying first differencing.

To determine the lag order of the TVP-VAR model and analyze the impact of LNPF on FFR, various information criteria such as AIC, SC, HQ were considered. Based on these criteria, a lag order of 2 was selected for the model.

3.2. Estimation Results of the Parameters

Using the Matlab software, a TVP-VAR model with two variables was estimated. The lag order was set to 2, following the approach of Nakajima et al. The prior distribution was specified as the starting point for MCMC (Markov Chain Monte Carlo) simulation, and a total of 10,000 samples were drawn. The first 10% of the samples were discarded, and the validity and convergence of the posterior distribution were examined.

Table 3 shows that based on the Geweke diagnostic test for convergence, the null hypothesis of convergence of the estimation results cannot be rejected at a significance level of 5% (below 1.96%), and all ineffective factors are at low levels. Therefore, it can be concluded that the estimation results have good convergence and validity, and the empirical findings are reliable.

Table 3. Results of the Augmented Dickey-Fuller (ADF) Test

Parameters	Mean	Standard deviation	95% Bayesian confidence Interval	Geweke test	Ineffective factors
Sb1	0.0023	0.0003	[0.0018,0.0029]	0.387	4.84
Sb2	0.0023	0.0003	[0.0018,0.0029]	0.330	3.04
Sa1	0.0088	0.0188	[0.0037,0.0402]	0.021	31.30
Sh1	0.0055	0.0015	[0.0034,0.0092]	0.512	15.54
Sh2	1.2582	0.0181	[0.0097,0.0166]	0.317	71.83

3.3. Time Varying Effect Analysis

Unlike conventional fixed-parameter models, the TVP-VAR model has time-varying characteristics and can generate an impulse response curve at each time point. Therefore, there are two main ways to present the experimental results: equally spaced impulse response and pointwise impulse response. To obtain an equally spaced impulse response, a fixed lead period, such as one month, is selected, and points corresponding to the one-month lead period in the impulse response curves at each time point are sequentially connected. The equally spaced impulse response shows the impact of the independent variable on the dependent variable after a fixed lead period, reflecting the time-varying relationship between variables throughout the study period. The pointwise impulse response refers to the gradually decaying impact of a shock from the independent variable on the dependent variable at a specific time point. To fully understand the influence of the US Federal Funds Rate (FFR) on the WTI crude oil futures price index (LNPF), we construct both equally spaced and pointwise impulse response functions and analyze the results.

The equally spaced impulse response graph illustrates the impact of a 1-standard deviation shock in the independent variable on the dependent variable at different time periods. We select three, four, and five periods to simulate short-term, medium-term, and long-term impulse responses, respectively. Figure 2 displays the equally spaced impulse response: the left graph represents the equally spaced impulse response of LNPF to itself, and the right graph represents the equally spaced impulse response of LNPF to FFR.

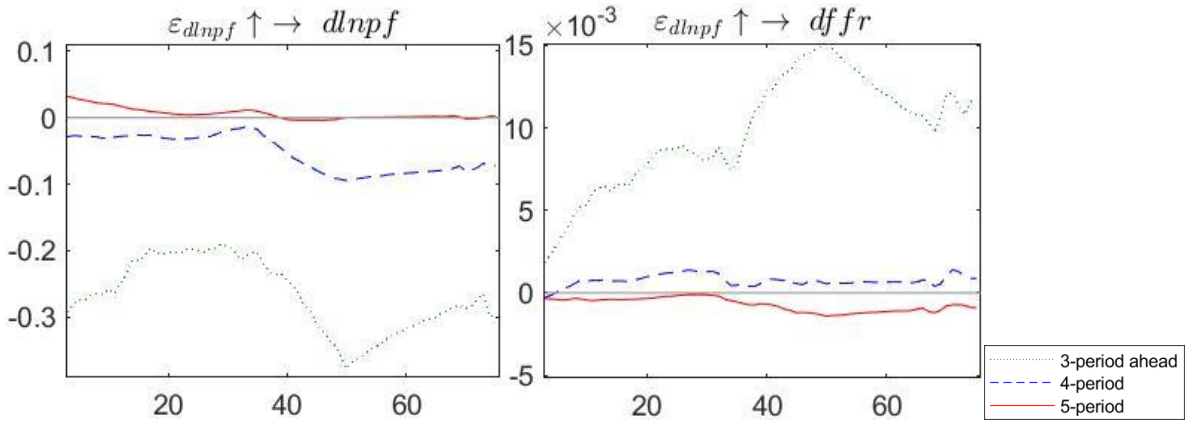


Fig 2. Equally spaced impulse response

As shown in Figure 2, when there is a positive shock to the WTI crude oil futures price (LNPF), it exhibits a negative response in the short and medium term but a positive response in the long term. On the other hand, when there is a positive shock to the U.S. federal funds rate (FFR), we observe a positive response in the short term of LNPF towards FFR, and this positive response is also present in the medium term. However, in the long term, LNPF shows a negative response to FFR. According to the impulse response analysis results, the impact of FFR on LNPF has a temporal nature. When FFR shocks LNPF, it initially generates a positive feedback which then turns into negative feedback after a lag of five periods.

The impulse response plots at different time points reflect the pulse response of the dependent variable to the independent variable. Specifically, the time points selected are August 2017 (t=20), April 2019 (t=40), and December 2020 (t=60). In Figure 3, the left plot shows the impulse response of WTI crude oil futures price (LNPF) to itself at different time points, while the right plot shows the impulse response of LNPF to the U.S. federal funds rate (FFR) at different time points.

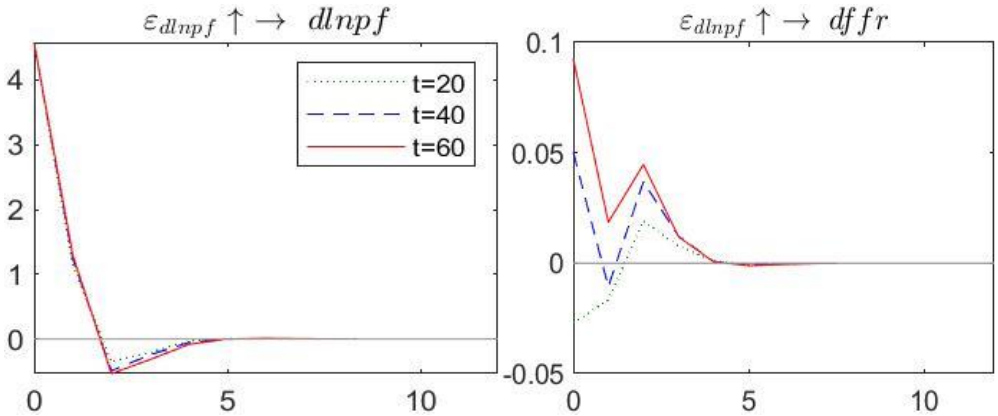


Fig 3. Impulse Response at different time points

As shown in Figure 3, WTI crude oil futures price (LNPF) exhibits varying degrees of positive response to the U.S. federal funds rate (FFR) at three different time points. The most intense negative response occurs in the third period of December 2020, followed by a trend towards zero response in subsequent periods. The short-term positive response observed in 2020 may be attributed to the sudden outbreak of the pandemic and the implementation of quantitative easing measures by the Federal Reserve. People anticipated inflation in the United States, leading residents to consider crude

oil futures as a hedge asset. Consequently, there was an increase in the price of crude oil futures in the short term due to the expectation that the FFR hike would stimulate the growth of LNPF. However, as the pandemic became more controlled later on, it was expected that the Federal Reserve would not allow inflation to continue rising. In this scenario, the FFR would have no impact on the fluctuation of LNPF.

4. Conclusion and Recommendations

Commercial banks should adjust the domestic fund allocation structure, lower the borrowing threshold for new energy enterprises, and the central bank can facilitate financing for small and medium-sized new energy enterprises by reducing the loan market quoted interest rate. Additionally, Chinese enterprises should be encouraged to use crude oil futures as a hedging asset, and there should be strengthened management of inflation expectations and forward-looking judgment. Furthermore, efforts should be accelerated to transform and upgrade the crude oil industry, formulate a new energy strategy aligned with high-quality socio-economic development, and enhance the intelligence and cleanliness of new energy development. Specifically:

(1) Considering the current global environment of quantitative easing, the banking system should adjust its domestic fund allocation structure to address the efficiency issues in allocating funds to new energy enterprises. Currently, state-owned enterprises and large energy companies that do not require capital receive a large amount of credit, while start-up new energy enterprises established in line with the "carbon neutrality" policy find it difficult and expensive to obtain financing. Therefore, apart from government subsidies, commercial banks should lower the borrowing thresholds for new energy enterprises. The central bank can leverage the window period before the Federal Reserve's interest rate hike to reduce the loan market quoted interest rate (LPR) and facilitate financing for small and medium-sized new energy enterprises.

(2) With regard to the expectation of a Federal Reserve interest rate hike, Chinese enterprises should be encouraged to use crude oil futures as a hedging asset. China has already established a crude oil futures market, and efforts should be made to encourage enterprises in the petrochemical industry to engage in transactions on the Shanghai crude oil futures market. By adopting a strategy that combines physical and financial investments, effective management of raw material prices can be achieved. At the same time, the influence of Chinese crude oil financial derivatives on commodities in the petrochemical industry chain should be expanded, establishing the INE crude oil futures as an authoritative benchmark for pricing. This will help build the Shanghai crude oil futures market into a standardized and effective futures market that can assist domestic enterprises in mitigating risks associated with international crude oil price fluctuations, thereby reducing the impact of the bursting of the U.S. inflation bubble on China's energy economy. Encouragement should be given to domestic consumption-oriented state-owned enterprises to hold Shanghai crude oil futures and gradually increase their positions, strengthening strategic cooperation with the Shanghai International Energy Exchange.

(3) From the perspective of U.S. inflation, participants in the Chinese crude oil market should strengthen inflation expectation management and forward-looking judgment. As of February 10, 2022, the consumer price index in the United States stood at 0.6%, and it is expected that the Federal Reserve will not allow the inflation rate to continue rising. Currently, economic development in various provinces in China is not balanced. On one hand, differentiated energy economic policies can be implemented to enhance the ability of less-developed regions to resist inflation. On the other hand, communication between the central bank and the public should be improved, with increased information disclosure and communication from the central bank playing a role in guiding and shaping public expectations. Reasonable inflation targets should be set to scientifically guide inflation expectations and maintain economic and social stability.

(4) Regarding China's imported crude oil structure, efforts should be accelerated to transform and upgrade the crude oil industry. During periods of high oil prices, China has paid a heavy price to

achieve its crude oil reserve strategy. Therefore, in the face of continued high international crude oil prices, China should formulate a new energy strategy that is aligned with high-quality socio-economic development, striving to improve the intelligence and cleanliness of new energy development. On one hand, in the petrochemical field, key refining technologies should be further strengthened through research, gradually increasing capital investment and policy support for the new energy industry, laying a solid foundation for China's energy transformation. On the other hand, by utilizing high-tech, backward, high-energy-consumption, and low-quality production capacity in the traditional energy industry should be transformed and upgraded into green, low-carbon, and high-quality production capacity, enabling the transformation of traditional energy into suitable and intelligent energy development.

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