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Dynamic Analysis of the Nonlinear Relationship Between Key Metal Prices and New Energy Vehicle Market

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Abstract. Up against the global energy transformation, the new energy vehicle industry has been in a stage of rapid development. Key metals represented by nickel are indispensable raw materials supporting the new energy vehicle industry, with their price fluctuations influencing its development, thereby affecting the global energy transformation. Studying the dynamic nonlinear relationship between the price fluctuation of the nickel as the key metal and the new energy vehicle market will provide a new perspective for understanding the dynamic development of the new energy vehicle market. Based on nickel price data, new energy vehicle market index, combined with Markov vector autoregressive model and cumulative impulse response function, this paper conducts research on the impact of nickel price fluctuations on the new energy vehicle market. According to the empirical results, the impact of nickel price fluctuations on the new energy vehicle market is different under various regimes. During the low-speed and high-speed development periods, nickel price fluctuations have a negative impact on the new energy vehicle market. During the stable development period, nickel price fluctuations mainly have a positive impact on the new energy vehicle market. Based on the above conclusions, this paper proposes policy suggestions for the relevant subjects.

Keywords: Nickel; New Energy Vehicle Market; MSVAR; Impulse Response.

1. Introduction

As the climate crisis becomes more severe and extreme weather occurs frequently, carbon neutrality and carbon peaking have been the focus of common attention all over the world. More and more countries have incorporated carbon neutrality into their national development strategies. More than 140 countries and regions around the world, including China, have proposed carbon neutrality goals to varying degrees, with the “Race to Zero” globally kicking off (ECIU, 2022). Since global energy transformation has become inevitable, at the general debate of the 75th UN General Assembly, China proposed the goal of “dual carbon”, striving to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 (Xi, 2020). The realization of the dual carbon cannot rely solely on energy conservation and emission reduction. Transforming the energy system is crucial to achieving the carbon peaking and carbon neutrality (Zhou, 2021).

The evolution sequence of the peak development of various industrial sectors in industrialized countries is consistent with that of the peak consumption of mineral resources required (Chen et al., 2015). Up against the goal of “dual carbon” and the industry 4.0 era, rare earths, lithium, cobalt, nickel and other key minerals are widely used in the new energy vehicle market, which have become vital raw materials for competition among major countries and economies in the world. In the next 20 years, the demand for minerals required for clean energy technology will increase by 4 times, the proportion of demand for metal cobalt and nickel will exceed 60%, and the demand for nickel triggered by the sales of electric vehicles will increase by 41 times (IEA, 2021). The surge in demand for nickel and other metals combined with the instability of supply has led to violent fluctuations in metal prices. As shown in Figure 1, the price of nickel will rise by more than 200% in 2020-2021. The rapid development of the new energy vehicle industry and other energy storage industries has largely stimulated the demand for lithium batteries. Lithium, cobalt, and nickel are raw materials for producing core devices such as power batteries and motors, and their price fluctuations have a great negative impact on the stability of the clean energy market. Hence, it is of great significance to study the price fluctuations of nickel and other metals as well as explore the impact of their price fluctuations on the new energy vehicle market.

Taking nickel, a key metal, as the research object, this paper aims to explore the nonlinear impact of nickel price fluctuations on the new energy vehicle market under different market conditions, so as to probe into its internal mechanism to provide scientific support for promoting global energy transformation.

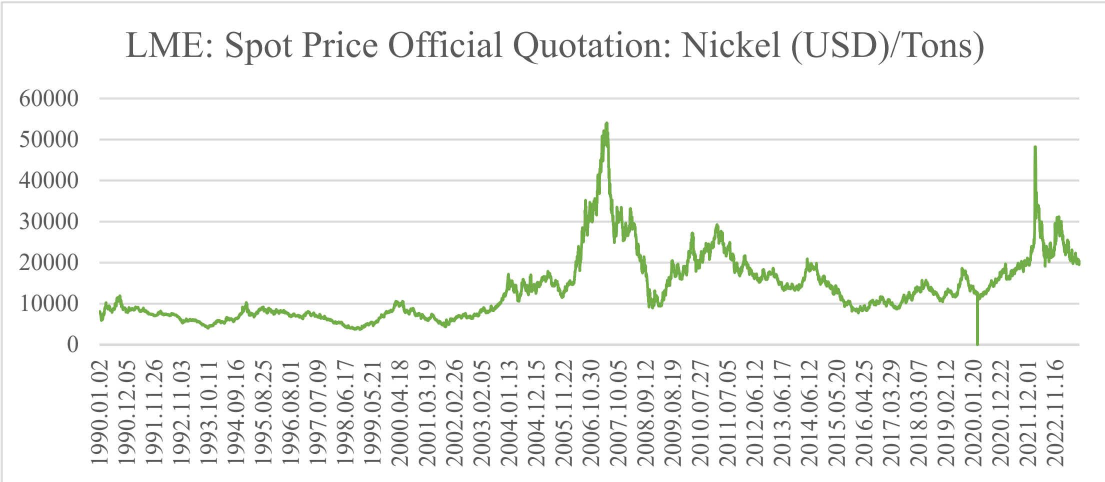

Figure 1. Chart of Changing Trend of Nickel Price
Source: Made by the Author from the Qianzhan Database (https://d.qianzhan.com)

2. Literature Review

According to existing studies, metal price fluctuations have apparent features such as agglomeration and persistence, which indicate relatively high price sudden changes (Zhang, 2015). Meanwhile, metal price fluctuations have an important impact on the industrial economy (Guo, 2018) with a two-way causal relationship between China's industrial growth and the overall price of metals (Wang and Wang, 2019). International metal price shocks have a negative impact on China's industrial output (Gao et al., 2018), and non-ferrous metal price shocks have a time-varying impact on China's industrial economy and nonlinear characteristics (Zhong et al., 2019; Zhong and Song, 2020; Wang et al., 2021; Shen and Huang, 2022). Fluctuations in international copper futures prices have brought uncertainty to industries such as electrical industry, electronics, automobiles, household appliances, and construction (Ma and Duan, 2018). Taking nickel as an example, more than 90% of China's nickel raw materials rely on imports. Since March 2022, international nickel metal futures prices have risen sharply and rapidly, and the rise in nickel prices has been transmitted to the new energy vehicle battery and vehicle industries (Ji, 2023). The relationship between clean energy and non-ferrous metals is time-varying and asymmetric. Besides, the stability of non-ferrous metals is crucial to mitigate uncertainty in the clean energy market (Muhammad et al., 2020). It can be seen that metal price fluctuations will trigger market fluctuations and changes in industrial development.

The Markov regime switching nonlinear model was proposed by Quandt in 1958 (Quandt, 1958). Sims proposed the VAR model in 1980, which is widely used in the macroeconomics to analyze and predict multiple related variables, such as studying the causal relationship and mechanism between the development of financial intermediaries and economic growth (Li and Chen, 2002), analyzing the price pass-through effect of the RMB effective exchange rate (Chen and Liu, 2007), and studying the impact of financial development on the quality of China's economic growth (Ma and Shi, 2012). However, the VAR model has limitations such as excessive parameterization and model settings that ignore the time-varying characteristics of economic structure, which makes it difficult to explain the nonlinear characteristics of the macro economy. In 1989, Hamilton proposed the Markov switching model (MS model), which assumes an intertemporal state correlation between variables to measure the dynamic autocorrelation of univariates and explore the nonlinear dynamic characteristics of univariates. In 1997, Krolzig extended Hamilton's single-variable autoregressive equation combined with the VAR model, and proposed the MSVAR model, which can be used to describe the nonlinear relationship between multiple variables. In recent years, MSVAR nonlinear models have been widely used, including the study of commodity futures and spot prices (Zhong et al., 2016; Kuang et al., 2021; Wang et al., 2021) as well as characterizing the phased characteristics of stock market fluctuations (Yan and Chen, 2009), etc.

To sum up, many scholars have conducted numerous research on the industry and market impact of metal price fluctuations with some progress and results, which laid a theoretical foundation for this research. However, most of the existing studies use methods such as SVAR model (Gao et al., 2018; Wang and Wang, 2019), ESTAR model (Cagli et al., 2019) or cross quantile correlation (CQC) (Uddin et al., 2019), which does not have time-varying function. At the same time, the analysis of the impact of existing research on metal price fluctuations mostly focuses on traditional metals or precious metals against the traditional industrial development (Elie et al., 2019; Dutta, 2019). Under the background of energy transition, there are few studies on how the key metals affect the clean energy market with certain research gaps, which are not conducive to a comprehensive understanding of the fluctuation correlation mechanism between metals and markets. Thus, it is of great significance to conduct in-depth research and exploration in the field of key metals and clean energy markets. This paper uses the MSVAR model to study the spillover effect of key metal price fluctuations on the international clean energy market, which can make up for the insufficient research in the existing literature on how key metals affect the clean energy market to a certain extent, and enrich the time-varying discussion on MSVAR model for time series research.

3. Data Sources and Research Methods

(1) Data Source

This paper mainly discusses the nonlinear impact of key metal price fluctuations on the new energy vehicle market. Nickel (Ni) is used as a key metal representative, and the New Energy Vehicle Market Index (Nea) is used to refer to the global new energy vehicle market. Markov switching vector autoregressive model (MSVAR) and cumulative impulse response are applied to study the nonlinear impact of nickel price fluctuations on the new energy vehicle market (Ni-Nea). The time duration of the sample data is from January 2015 to May 2021, a total of 77 months, which is long and includes multiple crucial economic events. All time series are monthly data, where the nickel (Ni) spot price data comes from the London Metal Exchange (LME). In addition, Nea is composed of the largest and most liquid 50 A-share stocks (Dai, 2022). To prevent the bias of the research results caused by the "pseudo regression" of the non-stationary time series, the ADF test is conducted on the above data first, and the first-order differential data pass the stationary test. The paper carries out normalization processing on the above data, which conducts BDS test on the nonlinear relationship between nickel price and new energy vehicle market index, with the above data passing the BDS test.

(2) Descriptive Statistics

Table 1. Descriptive Statistics

Type	Ni	NEA
Mean	12427.84	2244.517
Median	12300	2248.14
Maximum	19689	3950.054
Minimum	8120	1402.442
Standard Deviation	2534.994	510.3667
Skewness	0.399432	0.722866
Kurtosis	2.497351	3.548086
Sample Size	1515	1515

Table 1 shows the results of descriptive statistical analysis of 1515 daily sample data. According to Table 1, the average price of nickel is about 12,427.84 US dollars/ton, and the average index of the new energy vehicle market is 2,244.52 yuan. Based on the standard deviation data, the volatility of the new energy vehicle market index is significantly greater than that of the new energy market index. Moreover, the skewness of nickel price series and new energy vehicle market index series is greater than 0, which proves a right bias. The kurtosis of the price series of nickel is less than 3 with a peak, while that of the new energy vehicle market index series is greater than 3 with a flat peak.

(3) Introduction to Research Methods

1. Markov Regime Switching Vector Autoregressive Model (MSVAR)

Markov switching model is a nonlinear econometric model proposed by Quandt (1958), which has been developed under the research of Goldfeld (1973), Hamilton (1990) and other scholars. Since Sims (1972) et al. proposed the vector autoregression model (VAR), the combination of Markov switching model and VAR is often used to study their relationship. MSVAR model is based on the VAR, adding the features of Markov chains. Besides, in the VAR model, the influence of the explanatory variables on the explained variables in each period remains unchanged. The MSVAR model studies the relationship between the variables under different regimes. Each variable can form an n-dimensional time series vector ($Y_t = Y_{n1}, Y_{n2}, \cdots Y_{nt}$). The VAR model with a lag number of p-order is defined as: $Y_t = v_t(S_t) + A_1(S_t)Y_{t-1} + \cdots + A_p(S_t)Y_{t-p} + \varepsilon_t$, where S_t is a state variable with its value an interval [1, 2, 3]. $v_t(S_t)$ and A_p are intercept terms and parameter matrices under different regimes. ε_t meets the requirements of $\varepsilon_t: IID(0, \varepsilon)$. The MS model is a regime switching model (RS), with the RS probability as $P_{ij} = P_r(S_{t+1} = j | S_t = i)$, where P_{ij} is the probability of switching from state i to state j, and $\sum_{j=1}^{3} P_{ij} = 1, \forall i, j \in \{1, 2, 3\}$ with the third-order switching probability matrix as follows:

$$P = \begin{bmatrix} \mathrm{p}_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \tag{1}$$

Krolzig (1997) divided MSVAR models into four categories, including MSM-VAR, MSI-VAR, MSA-VAR, and MSH-VAR according to the differences in mean, intercept, autoregressive coefficient, and error terms. Specifically, M represents the mean, I represents the intercept, A represents the autoregressive coefficient, and H represents the variance of the error term. There are two methods of parameter estimation in MSVAR model: EM algorithm and GIBBS sampling algorithm. This paper obtains parameter estimation based on EM algorithm.

Through the regime study of Ni-Nea through MSVAR, we can explore the dynamic changes of the impact of nickle price fluctuations on the new energy vehicle market (Ni-Nea) under different market conditions and identify the heterogeneous characteristics of market changes under different market conditions. In terms of model construction, based on the practice of dividing the metal market regime (Zhong et al., 2016; Shen and Huang, 2022), the paper selects the three-regime MSVAR model. According to results of Eviews analysis, the optimal lag order of the selected variable is 4. Givewin2.0 is used to select MSVAR model in Ocmetrics3.4, combined with the principle of maximum Log-likeihood, minimum AIC, HQ, SC. In addition, MSIH (3)-VAR (4) model has high accuracy and fit. Hence, this paper uses MSIH (3)-VAR (4) model to model Ni-Nea, and conducts state-dependent impulse response.

2. State-Dependent Impulse Response

The state-dependent impulse response function is used to describe the relationship between data, which can explain the correlation and disturbance relationship between random variables. In impulse response function, different order of variable data will produce different impulse response function graph. If K is the number of variables in the model and m is the number of regime states, K

impulse response functions will be generated, and mK^2 impulse response function graphs can be estimated. The impulse response function is expressed as follows:

$$\frac{\partial E_t X_{t+h}}{\partial u_{k,t}}|_{S_t=\cdots=S_{t+h}} = \theta_{ki,h}, h \geq 0 \quad (2)$$

Where i represents the i-th regime, t represents the time, k represents the variable, and h represents the number of tracking periods.

To further investigate the direction, duration and intensity of the impact of nickle price fluctuations on the new energy vehicle market (Ni-Nea) in various regions, and compare the differences in dynamic impacts under various regions, the paper uses state-dependent impulse response for analysis. A standard deviation is given to the nickel price to observe the impact of nickle price fluctuations on the new energy vehicle market (Ni-Nea) under various regions.

4. Result Analysis

According to Figure 2 that shows the fluctuations of each economic variable in the MSIH (3)-VAR (4) model, there are three changes in the Ni-Nea market, including "high volatility", "low volatility" and "stability". Figure 3 is the probability distribution map of the regime, where the horizontal axis means time, and the vertical axis means the probability of economic variables in a regime. Combining the division of metal price fluctuation regime (Zhong et al., 2016; Wang and Fan, 2019; Wang et al., 2021) and the fluctuation of each variable in Figure 1 and the actual economic development, the regime 1 is defined as low-speed development regime, the regime 2 as stable development regime, and regime 3 as high-speed development regime.

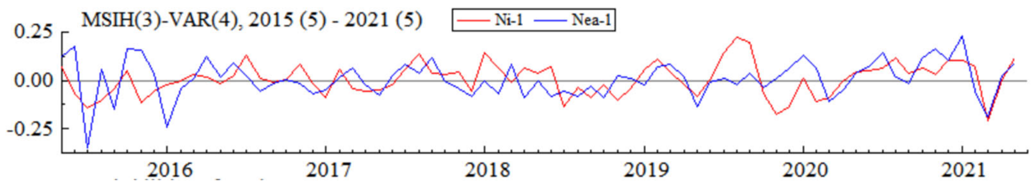

Figure 2. Fluctuation Diagram of Each Variable in the MSIH (3)-VAR (4) Model

According to Figure 3, most samples within the sample range fall into the regime 2, that is, the stable period. Secondly, before 2016, the sample was mainly distributed in the regime 1, that is, the low-speed development regime. Affected by the Paris Agreement, the economic system has entered a period of stable development. After 2019, there have been continuous changes among three regional systems. The listing of many new energy vehicle companies in 2018 has been in a short period of rapid development in the Ni-Nea market. From 2020 to 2021, the global economy was hit hard by COVID-19 pandemic and the economic system volatility is violent, so it has experienced a switch from "low volatility-stability-high volatility-low volatility" within a year. With the rapid development of the new energy vehicle industry in 2020 and the sharp rise of Bitcoin, the Ni-Nea market has been in a rapid development in early 2021. Thus, the Ni-Nea market was first in a low-speed development during the sample period, and then turned to a stable stage. Since 2019, it has changed between the three regimes and finally fell into the high-speed development regime. This indicates that the Ni-Nea market is generally developing steadily. However, due to factors such as COVID-19 pandemic's impact on the global economy and the international turmoil, the Ni-Nea market has continued to fluctuate since 2019. However, with the rapid development of the new energy industry up against the energy transition, the Ni-Nea market will maintain rapid development in the future.

Table 2 shows the switching probabilities and properties between various regimes. The probability of each regime maintaining the market state represents the stability in each regime. Based on the switching probability of the regime, after the Ni-Nea market enters the regime 1 (low-speed development regime), the probability of maintaining this state is 0.75. The probability of switching from the regime 1 to regime 2 (stable regime) is 0.14, that of switching from regime 1 to regime 3 (high-speed development regime) is 0.11, and that of maintaining regime 2 (stable regime) is 0.96, which proves that during the sample period, the Ni-Nea market state generally presents a switching path of three states, including "low-speed development -stable development-high-speed development". Besides, the probability of suddenly entering a high-speed development from a stable period is not high, the probability of switching to a low-speed development is close to 0, and the probability of switching from a high-speed development to a stable development is also close to 0. Hence, it is generally in a stable development. After 2021, the Ni-Nea market will switch between high-speed development and low-speed development regime, and the probability of maintaining regime 3 is higher than that of switching to other regimes. It can be seen that the future market will be in a high-speed development regime.

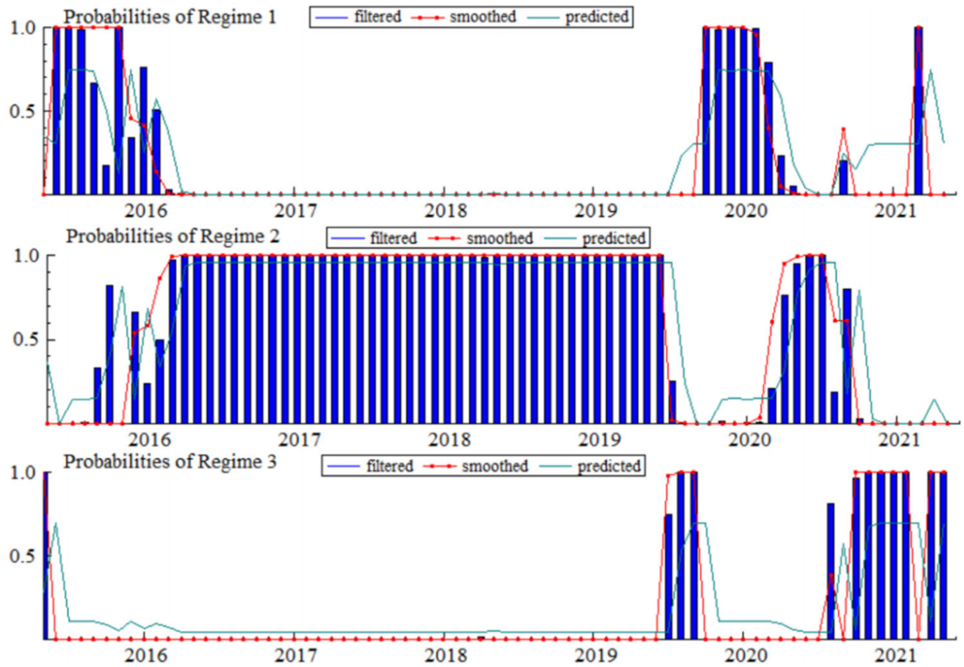

Figure 3. Regime Switching Probability Diagram (Ni-Nea)

Table 2. MSIH (3)-VAR (4) Model Regime Switching Probability Matrix and Regime Characteristics

Regime Switching Probability				Regime Switching Property			
	Regime 1	Regime 2	Regime 3		Number of Observations	Probability	Duration
Regime 1	0.75	0.14	0.11	Regime 1	13.80	0.19	3.99
Regime 2	0.00	0.96	0.04	Regime 2	47.80	0.65	23.42
Regime 3	0.31	0.00	0.69	Regime 3	11.40	0.16	3.26

Note: Only two decimal places are reserved for the figures in this table.

It can be seen from the switching property of the regime that in the sample interval, about 13.8 observations are in the regime 1, 47.8 observations are in the regime 2, and 11.4 observations are in the regime 3. Each observation has 0.19 probability of being in regime 1, 0.65 probability of being in regime 2, and 0.16 probability of being in regime 3. During the sample period, most samples fell in the stable period, and the duration was 23.42 months.

According to the above results, most of the Ni-Nea market is in a stable development during the sample period, and the Ni-Nea market presents a three-state switching path of the “low-speed development-stable development-high-speed development”. Besides, Ni-Nea market will be in high-speed development in the end of sample period and maintain such a rapid development for a long time.

Based on the MSIH (3)-VAR (4) model estimation, the nonlinear impulse response function is used to further investigate the impact of nickel price fluctuations on the new energy vehicle market, and compare the differences in the dynamic relationship of the variables studied under different regimes, with the specific results shown in Figure 4.

According to Figure 4 that shows the impact of nickel price fluctuations on the new energy vehicle market under different regimes, when the nickel price is positively impacted by one unit, the impact of nickel price fluctuations on the new energy vehicle market in different regimes is not the same. In the regime 1, that is, in the period of low-speed development, the impact of nickel price fluctuations on the new energy vehicle market is always negative, which shows a state of periodic fluctuations. From the current phase to the Phase 1, it reaches the minimum negative response. In the Phase 4, it reaches the maximum negative response. The response reached the second peak in the Phase 6, the response in the Phase 6 to the Phase 8 strengthened, and finally stabilized in the Phase 13 with a cumulative negative response of about 0.025. In the regime 2, that is, in the period of stable development, the current response is positive and the maximum positive response is reached in Phase 1-2. Then, the response weakens, turns negative in Phase 3 and reaches the maximum negative response in Phase 4. In addition, the response turned positive after Phase 5, reached the second peak in Phase 6-7, and stabilized in Phase 10 with a cumulative negative response of about 0.01. In the regime 3, that is, the period of rapid development, the response of the new energy vehicle market to nickel price fluctuations is always negative, and the response is stronger than that of regime 1 and regime 2. The maximum negative response is reached in the current phase, and then the response weakens. In the Phase 14, the response tends to be stable and the cumulative negative response is about -0.07.

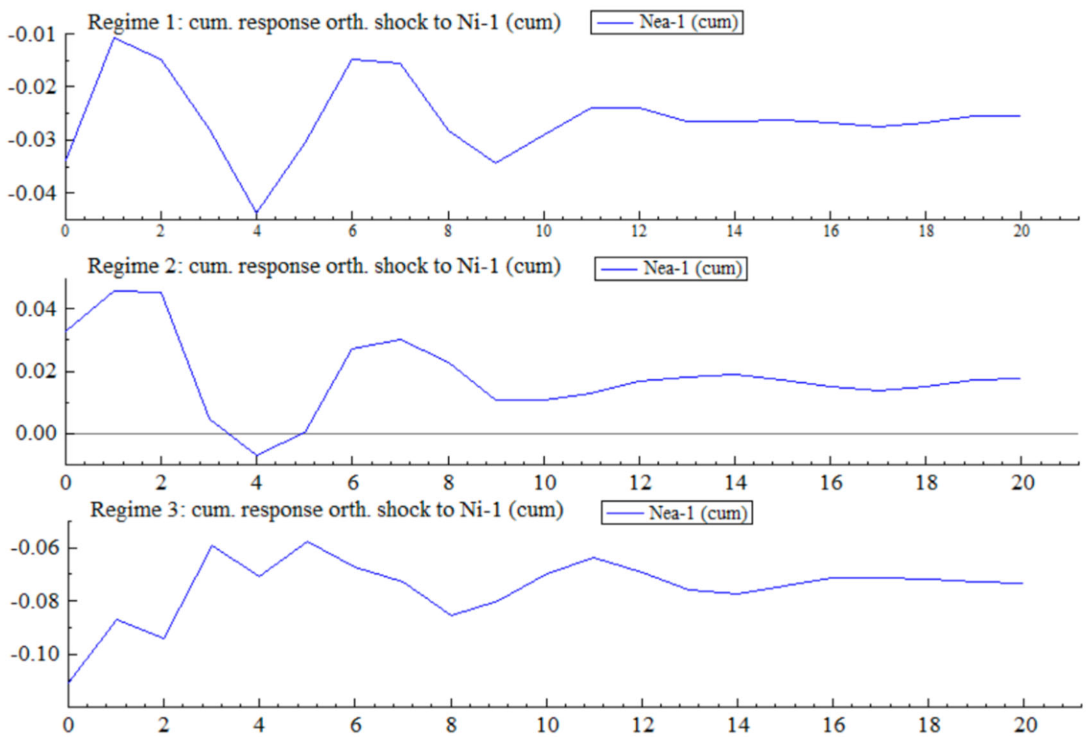

Figure 4. Impulse Response Chart

It shows that in the period of low-speed development and high-speed development of the market, fluctuations in nickel prices slow down the development of the new energy vehicle market, while in the period of stable development, fluctuations in nickel prices have both positive and negative impacts on the new energy vehicle market, mainly presenting a positive impact.

5. Robustness Test

To enhance the credibility, this paper selects the new energy market as a variable to test the nonlinear dynamic relationship between key metals and the new energy market as a robustness test to support the results. According to the results, the Ni-Zne market is mostly in a stable period during the sample period, and the Ni-Zne market correlation presents a three-state switching path of "low-speed development-stable development-high-speed development". In the end of the sample period, the Ni-Zne market is in a rapid development. In the period of low-speed development, fluctuations in nickel prices will slow down the development of the new energy market. In the period of high-speed market development, changes in nickel prices will promote the new energy market. In the period of stable development, fluctuations in nickel prices will have positive and negative impacts on the new energy market. However, generally speaking, there is a negative impact, with relevant empirical results found in supplementary materials.

6. Conclusions and Suggestions

Combining the monthly data of the new energy vehicle market index and the spot price of nickel, this paper conducts a study on the impact of nickel spot price fluctuations on the new energy vehicle market based on the MSVAR model and impulse response function method.

The empirical results show that the fluctuation of nickel spot price will have an impact on the new energy vehicle market, and the impact varies under different development regimes. For the new energy vehicle market, during the low-speed development period and the high-speed development period, fluctuations in nickel prices will slow down the development of the new energy vehicle market, while during the stable development period, fluctuations in nickel prices will have both positive and negative impacts on the new energy vehicle market, but mainly presenting positive impact.

Combined with the research conclusions, this paper puts forward the following policy suggestions. The state should play a macro-control role in the market to promote the steady development of the new energy vehicle market. The development of new energy is a long-term process. During the period of rapid market development, it is necessary to maintain the stability of the metal market and prevent and control its excessive expansion caused by nickel price fluctuations, which will weaken future development. In the period of low-speed market development, the state can encourage investors to purchase stocks in the new energy vehicle market through relevant preferential tax policies to prosper the new energy vehicle market. Market regulators should maintain the openness and transparency of the metal trading market, improve relevant trading websites to realize real-time updates of trading information, and reduce the impact of false information dissemination on market prices. Besides, investors can refer to the current new energy vehicle market and the probability of regime switching to predict the future market development, avoid investment risks, and obtain investment returns. Meanwhile, attention should be paid to the impact of nonlinear methods on the metal market and the new energy vehicle market. Herd mentality should be abandoned to guide investment decisions with rational thinking.

With some limitations, this paper takes the spot price of nickel as the research object, which fails to conduct research on the industrial chain or consider the impact of nickel price fluctuations on the upper, middle and lower reaches of the industrial chain. In the future, we can study the impact of nickel spot price fluctuations on the new energy vehicle market from the perspective of the entire industry chain based on material flow or complex network methods, or study the impact of the new energy vehicle market on nickel spot prices.

References

[1] Chen, L. F. & Liu, H. J. (2007). Price pass-through effect of RMB exchange rate—Empirical analysis based on VAR model. Journal of Financial Research, (04): 1-13.

[2] Ji, X. T. (2022). Rising nickel prices may affect the direction of new energy vehicle battery technology. China Electric Daily. Accessed on 2022-03-25(008).

[3] Kuang, Q. H., Liu, C. X. & Yin, H. (2021). Research on factors affecting international price fluctuations of nonferrous-metallic mineral resources under the background of dual circulation—Taking copper and tin as examples. Prices Monthly, (09): 1-9. DOI:10.14076/j.issn.1006-2025.2021.09.01.

[4] Li, G. Z. & Chen, P. (2002). Financial intermediary development and economic growth: A multi-variable VAR system study. Journal of Management World, (03): 52-59. DOI:10.19744/j.cnki.11-1235/f.2002.03.008.

[5] Ma, H. X. & Duan, B. N. (2018). Impact of international copper price fluctuation on China's economy. Enterprise Economy, 37(05): 39-48. DOI:10.13529/j.cnki.enterprise.economy.2018.05.006.

[6] Ma, Y. Q. & Shi, A. N. (2012). Research on the impact of the financial development on economic growth quality in China—Based on VAR model. Studies of International Finance, (11): 30-39.

[7] Shen, J. J. & Huang, S. P. (2022). Structural shocks of international copper price fluctuation on China's industrial economy: Based on MSVAR and TVP-SVAR-SV models. Resources Science, 44(05): 994-1008.

[8] Wang, D. Y., Huang, Y. Q., Cheng, J. H. et al. (2021). The spillover effects of nonferrous metal price fluctuations—A nonlinear analysis of China's industrial economy at different stages. Journal of Industrial Technology and Economy, 40(06): 126-133.

[9] Wang, M. & Fan, Y. P. (2019). Relationship between market sentiment, iron ore future prices and spot prices based on the MSVAR model. China Mining Magazine, 28(04): 20-25+38.

[10] Yan, T. H. & Chen, M. Y. (2009). Analyze the SSE (Shanghai Stock Exchange) composite index week returns ratio with time series analysis method based on Markov switching model. Chinese Journal of Management Science, 17(06): 33-38.

[11] Zhang, F. L. (2015). Analysis of commodity futures price behavior based on Markov switching MSVAR model. Statistics & Decision, (13): 158-161. DOI:10.13546/j.cnki.tjyjc.2015.13.043.

[12] Zhong, M. R., Shen, J. Y., Huang, J. B. et al. (2016). Nonlinear effect studies of influence factors of nonferrous metals price fluctuation based on MSVAR model. Chinese Journal of Management Science, (04): 45-53.

[13] Zhong, M. R. & Song, W. T. (2020). Impact of strategic metal price shocks on industrial output: Time-varying analysis based on the TVP-FAVAR model. Resources Science, 42(08): 1580-1591.

[14] Abdul, A. (2003). Early warning systems: A survey and a regime-switching approach. IMF Working Papers. 03.10.2139/ssrn.581141.

[15] Dai, Z., Zhu, H. & Zhang, X. (2022). Dynamic spillover effects and portfolio strategies between crude oil, gold and Chinese stock markets related to new energy vehicle. Energy Economics. 109,105959.

[16] Dutta, A. (2019). Impact of silver price uncertainty on solar energy fifirms. J Clean Production, 225:1044e51.

[17] Cagli, E. C., Taskin, D. & Mandaci, P. E. (2019). The short- and long-run efficiency of energy, precious metals, and base metals markets: Evidence from the exponential smooth transition autoregressive models. Energy Economics, (84), 104540, ISSN 0140-9883.

[18] Elie, B., Naji, J, Dutta, A. & Uddin, G. S. (2019). Gold and crude oil as safe-haven assets for clean energy stock indices: Blended copulas approach. Energy, 544e53.

[19] Gao, C., Huang, J. B., Chen, J. Y. et al. (2018). Industrial transmission effect of international metal price shocks in perspective of industry chain. J. Cent. South Univ. 25, 2929-2943.

[20] Hamilton, J. D. (1989) A new approach to the economic analysis of nonstationary time series and the business cycle. Econometrica, 57, 357-384.

[21] IEA (2021). The role of critical minerals in clean energy transitions. IEA, Paris

[22] Jin, G. (2018). Co-movement of international copper prices, China's economic activity, and stock returns: Structural breaks and volatility dynamics. Global Finance Journal, (36), Pages 62-77. ISSN 1044-0283.

[23] Zhong, M. R., He, R. F., Chen, J. Y. & Huang, J. B. (2019). Time-varying effects of international nonferrous metal price shocks on China's industrial economy. Physical A: Statistical Mechanics and its Applications, (528), 121299. ISSN 0378-4371.

[24] Sims, Christopher A. (1972). "Money, income, and causality." The American Economic Review, 62(4), 540-52. JSTOR.

[25] Stephen, M., Richard, G. & Quandt, E. (1973). A Markov model for switching regressions. Journal of Econometrics, 1(01), 3-15. ISSN 0304-4076.

[26] Teske, S., Florin, N., Dominish, E. & Giurco, D. (2016). Renewable energy and deep-Sea mining: Supply, demand and scenarios.

[27] Wang, T. & Wang, C. F. (2019). The spillover effects of China's industrial growth on price changes of base metal. Resources Policy, 61, 375-384. ISSN 0301-4207.

[28] Uddin, G. S., Rahman, M. L., Hedstrom, A. & Ahmed, A. (2019). Cross-quantilogram-based correlation and dependence between renewable energy stock and other asset classes. Energy Economics, 80: 743e59.