The Impact of Carbon Risks on Energy Company Stock Prices: An Empirical Study based on Investor Concerns

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Abstract. Based on a Baidu index perspective, this paper constructs an intermediary effect model and a VAR model to investigate the impact of carbon risk and investor concerns on the share prices of energy companies, using daily data on the closing prices of energy company stocks and trading on eight carbon emission rights exchanges. The results show that there is a long-term interaction among carbon risks, investor concerns and energy company share prices. Analysis of the intermediary effect shows that investor concerns have a positive intermediary effect, reinforcing the response of corporate share prices to carbon risk. Finally, the paper makes recommendations for the investment decisions of Chinese investors, the strategic development of energy companies and the development of the carbon emission rights trading market.

Keywords: Carbon Risks; Stock Price; Investor Concerns; VAR Model; Baidu Index; Intermediary Effect.

1. Introduction

In recent years, due to the increasingly severe climate change in the world, China has become the world's largest emitter of greenhouse gases and is also facing increasing international pressure on carbon emission reduction (Zhou Zhifang et al., 2019). Under the background of increasingly serious carbon pollution problem, the green economy is becoming more and more critical to the future economic growth of China. The Party Central Committee has made important strategic decisions to coordinate the domestic and international situations. Peaking carbon dioxide emissions and carbon neutrality are important ways to solve the outstanding problems of resource and environment constraints, and the inevitable choice to realize the sustainable development of the Chinese nation, as well as the solemn commitment to build a community of shared future for mankind. After the "30· 60" policy was issued, China's carbon market will usher in rapid development and play a key role in the process of carbon neutralization.

Carbon trading has become a major means to combat climate change and is considered to be the most cost-effective carbon reduction tool (Bu Wenke and Zhao Meng'en, 2020). In July 2021, China's national unified carbon emission rights trading market fully launched carbon trading (Li Jiangtao and Tao Siyuan, 2022). On January 2, 2023, the *Report on the First Performance Cycle of China Carbon Emission Rights Trading Market* pointed out that the trading volume of carbon emissions in the first performance cycle of China's carbon emission rights trading market economy totaled 7,661 million shares, and the trading volume of quotas totaled 179 million tons. The trading market was in stable and orderly operation, with trading prices mainly maintaining stable with rise. The establishment of the national carbon exchange suggests that the initial structure of China's carbon emission rights trading market has been completed. With the formation and improvement of the carbon emission rights trading market in China and the continuous increase in the cumulative trading volume of carbon emission quotas, the interaction between the value of the carbon trading market and other markets has attracted more and more attention. Energy companies have also begun to pay attention to the impact of the carbon trading market in China on the emission efficiency of enterprises, investment value and the development of their own companies (Zhao Lingdi and Wang Haixia, 2019).

The contributions of this paper mainly include the following four points: First, this research puts forward relevant suggestions for investors in China to make rational investment decisions. Second, this research fosters a sound carbon price formation mechanism, effectively utilizes the resource allocation effect of the capital market to drive energy conservation and emission reduction of energy companies and upgrade of the industrial structure, and actively promotes technological innovation and application of carbon finance. Third, this research calls on the energy companies to vigorously promote technological innovation, so as to promote the development of their own companies and the development of China's carbon emission trading market. Fourth, by introducing the variable of investor concerns, the paper explores the main influencing factors of energy companies' stock prices from a brand-new perspective, and calls for more companies and investors to participate in carbon emission rights trading, so as to increase the participation in carbon emission rights trading and enrich the vitality of carbon emission rights trading market.

2. Literature Review

2.1 Carbon Emission Rights Trading

The research on China's carbon emission rights trading mainly focuses on the theoretical aspects such as the volatility of carbon trading pricing, expectations of carbon price, influencing factors of carbon price, and the correlation with energy factors such as energy price and green innovation of enterprises. The first aspect is related research on carbon price formation, fluctuation of carbon price and spillover effect of carbon trading. Scholars, for example, Yang Min and Zhu Shuzhen (2022) put forward the principles and methods for determining the carbon price from the perspective of the national carbon trading market, including the principle of increasing the carbon price, the principle of convergence between the actual carbon trading price and the opening price, etc. Gong weifeng and Wang Liping (2022) took the five carbon emission rights trading markets in China as the research objects, and use GARCH-BP combination model to analyze the volatility characteristics of carbon trading price returns. This research found that the carbon trading price returns of each carbon trading pilot have very different responses to internal and external shocks, and their returns and risks have no relevant trend. At present, scholars' research on the spillover effect between China's carbon emission rights trading market focuses on the spillover effect of carbon price return rate and carbon price volatility. Lv et al. (2020) and Zhao et al. (2020) analyzed the change of carbon price return spillover effect between carbon markets, and found that carbon emission trading markets in China are closely related. The second aspect is the research on the relationship between carbon price and energy price. Chen Ke and Hua Jingfen (2022) established a vector autoregressive model (VAR), which showed that the impact of the price of fossil energy products on the market price of China's carbon emission rights trading has obvious regional differences. Liu Yifei (2021), taking Guangzhou as an example, found that the international energy price, GDP growth rate of the three major industries and the allocation scheme of carbon emission rights are the main reasons that directly affect the size and price of China's carbon emission rights trading market. Liu Junyang et al. (2020) believed that both the air quality index and the new energy index affect the fluctuation of carbon emission trading price.

2.2 Carbon Risks and Share Price of Energy Companies

Massari et al. (2016) pointed out that the carbon risk levels of enterprises in different industries are different, and the carbon risks mainly exist in companies that are directly or indirectly exposed to greenhouse gas emission restrictions. The current research mainly uses the following three methods to measure carbon risks based on direct carbon emissions. First, conduct research by using data on changes in carbon emission levels or total carbon emissions. For example, Bose et al. (2021) pointed out that enterprises with higher total carbon emissions have a higher probability of being sanctioned or internalizing external risks related to carbon risks. Other scholars extracted carbon emission scores from MSCI ESG ratings to measure environmental risk exposure at the enterprise level (Cao et al, 2021). Second, conduct research by using carbon intensity data. Some of the literature selected business income (Shive & Forster, 2020; Duan et al, 2020) or sales (Dai & Meyer-Brauns, 2020). Third, conduct research by using the ratio of experimental target carbon emissions to actual carbon emissions (i.e., carbon efficiency) is used. Trinks et al. (2020) proved that at the international level, the carbon efficiency level of an enterprise will have a positive impact on its return on assets (ROA) and market valuation. In recent years, scholars at home and abroad have carried out relevant research on the correlation between the company’s carbon emission data and asset prices, especially the stock return rate. Bolton and k acperczyk (2021 a) believe that, after controlling the scale, book value ratio and other factors that can reflect the stock return rate, the expected return on shares of companies with higher carbon emission level will be better, indicating that investors expect to get higher return from companies with higher carbon risk level. The same analysis holds true for carbon trading markets in developed countries (Bolton and Kacperczyk, 2021b). At present, there is little research on the role between carbon price and the internal mechanism of stock in China.

At present, although a lot of literature indicate the relationship between investor concerns and stock returns, few articles combine investor concerns with VAR model to explore the relationship among investor concerns and carbon risks and energy companies’ stock prices. Therefore, under the background of China’s emphasis on low-carbon economy and ecological environment protection, this paper explores the impact of carbon emission rights price on energy companies’ stock prices based on investor concerns, and provides evidence from China for carbon finance from both theoretical and empirical perspectives.

3. Variable Selection and Data Sources

3.1 Data Selection

3.1.1 Explained Variables

This paper selects 20 energy industry stocks among them to reflect the overall performance of energy companies’ share prices. The 20 energy companies rank high in market value and come from different regions in China with high representativeness. The daily closing prices of 20 representative energy companies in China are pre-processed as explained variables, and the data are from Wind database.

3.1.2 Intermediary Variables

This paper selects Baidu Index as the proxy of investor concerns, which is reasonable and representative in studying the impact of carbon risks on corporate stock price under investor concerns. Selecting three categories of keywords about carbon risks, energy and climate, and using Python to crawl the daily search volume of the selected 14 key words, and the data source is Baidu Index official website. After averaging the indices of the three key words, they are integrated into one index. This paper conducts a follow-up study on this index as investor concerns. See Table 1 for the selected keywords.

Table 1. Keyword Selection

Category	Keyword
Carbon risks	Carbon emissions, carbon footprint, carbon trading, low carbon, greenhouse gases
Energy	Energy saving, water saving, new energy and electricity saving
Climate	High temperature, cold wave, natural disasters, drought, rainstorm

3.1.3 Explanatory Variables

In this paper, eight major carbon emission rights trading markets in different provinces and cities in China are selected as research objects, including the newly opened carbon emission rights trading market in Fujian. The data source is Wind database.

3.1.4 Control Variables

In this paper, the turnover rate, Brent crude oil index and coal price index of the selected energy companies are added as control variables to reduce the error generated by the empirical analysis.

4. Empirical Analysis

4.1 Empirical Analysis based on VAR Model

4.1.1 Stationarity Test

Perform a unit root test on all variables to verify whether a unit root exists. If the display is unstable, the unstable variables are subjected to differential processing, and the processed variables are all stable. As shown in Table 2, after taking the first-order difference, the four variables of dlncarbon, doil, dcoal and dlnstock are all stable, and a VAR model can be established.

Table 2. Results of Robustness Test

Variable	ADF test value	*P* value	Stability state
lncarbon	-3.21023	0.0831	Unstable
dlncarbon	-19.9394	0.0000**	Stable
lnbaidu	-4.428990	0.0003	Stable
btr	-5.62502	0.0000**	Stable
oil	-2.26524	0.4521	Unstable
doil	-27.2222	0.0000**	Stable
coal	-1.86094	0.6737	Unstable
dcoal	-28.3998	0.0000**	Stable
lnstock	-2.01671	0.5908	Unstable
dlnstock	-27.7469	0.0000**	Stable

Note: * * indicates rejection of the original assumption at the level of 5%.

4.1.2 Johansen Co-integration Test

The Johansen co-integration test is performed to test whether the model has false regression. Only when the co-integration test is passed can we obtain an accurate empirical result. As shown in Table 3, the maximum characteristic root value and trace statistics are both highly significant, indicating that there is a long-term equilibrium relationship between the stock price of energy enterprises and carbon risk.

Table 3. Test Results of Characteristic Root Values

Null hypothesis	Eigenvalue	Trace statistics	*P* value	Critical value of 5%
NoneΔ	0.274766	709.1522	0.0001**	95.75366
At most 1Δ	0.200486	451.8222	0.0001**	69.81889
At most 2Δ	0.1451	272.5972	0.0001**	47.85613
At most 3Δ	0.123947	147.0239	0.0001**	29.79707
At most 4Δ	0.038332	41.02858	0.0000**	15.49471
At most 5Δ	0.012062	9.720451	0.0018**	3.841466

Note: * * indicates rejection of the original assumption at the level of 5%.

4.1.3 Selection of Hysteresis Order

Table 4. Hysteresis Order Results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-180.8641	NA	0.005418	0.457732	0.469455	0.462236
1	2231.583	4806.778	1.31e-05	-5.570921	-5.535752	-5.557410
2	2257.837	52.18051	1.23e-05	-5.626627	-5.568012	-5.604108
3	2277.138	38.26353	1.19e-05	-5.664927	-5.582866	-5.633401
4	2295.484	36.27827	1.15e-05	-5.700836	-5.595329*	-5.660303*
5	2300.013	8.93255	1.14e-05*	-5.702160*	-5.573206	-5.652618
6	2303.612	7.081455	1.15e-05	-5.701157	-5.548757	-5.642608
7	2304.808	2.346932	1.15e-05	-5.694138	-5.518292	-5.626582
8	2310.327	10.80275	1.15e-05	-5.697939	-5.498647	-5.621376
9	2315.694	10.48006*	1.15e-05	-5.701363	-5.478625	-5.615792

Note: * represents the best hysteresis order determined under different criteria.

As can be seen from Table 4, the optimal hysteresis order of the model is determined to be 5.

4.1.4 AR Test

The AR test can prove that the model is stable and effective to ensure the accuracy of further in-depth research. The AR test on the model shows that the reciprocal of all AR unit roots is less than 1 and evenly distributed in the unit circle with radius of 1, so there is no unit root, as shown in Figure 1.

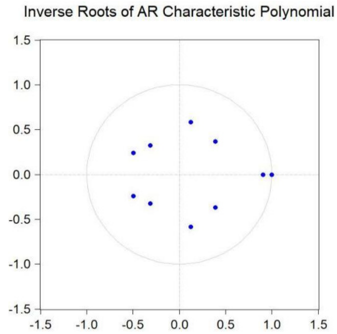

Fig 1. AR Test Results

4.1.5 Model Construction

Based on the above variable settings, this paper establishes a VAR model to study the impact relationship between carbon risks and energy company stock price from the perspective of investor concerns. Vector autoregressive model is a time series model, which uses all the current variables in the model to regress the lagged variables of all variables. Its expression is as follows:

$$y_t=A_1y_{t-1}+\ldots+A_py_{t-p}+Bx_t+\varepsilon_t$$
$$t=1, 2,\ldots,T \quad (1)$$

In this paper: yt represents the share price of energy companies, xt represents investor concerns and carbon risks, P represents hysteresis order, T represents the number of research samples, and εt is the perturbation term.

4.1.6 Granger Causality Test

Granger causality test is performed on each sequence, and the lag phase is selected as 1~5. As shown in Table 5, when the original assumption was that “fluctuations in the share price of energy companies will not cause changes in carbon risks”, the p value tested by Granger was 0.006513<0.05, rejecting the original assumption that fluctuations in the share price of energy companies will cause changes in carbon risks. When the original assumption is that “fluctuations in carbon risks will not cause changes in the share price of energy companies”, the p value tested by Granger is 0.008958<0.05, rejecting the original assumption that fluctuations in carbon risks will cause changes in the share price of energy companies. To sum up, there is a two-way causal relationship between energy companies’ share prices and carbon risks.

Table 5. Granger Causality Test Results

Original hypothesis	F statistics	*P* value	Conclusion
Lnstock is not Granger Cause of lncarbon	0.66343	0.0065**	Reject
Lncarbon is not Granger Cause of lnstock	0.32862	0.0089**	Reject
Lnbaidu is not the Granger cause of lnstock	4.99862	0.0481**	Reject
Lnstock is not the Granger Cause of lnbaidu	1.29803	0.0262**	Reject
Lnbaidu is not Granger Cause of lncarbon	1.577728	0.1164**	Accept
Lncarbon is not Granger Cause of lnbaidu	1.41926	0.0214**	Reject

Note: * * indicates rejection of the original assumption at the level of 5%.

4.1.7 Impulse Response

lncarbon, lnstock and lnbaidu are subjected to impulse response processing respectively. As can be seen from Figure 2, the carbon risk reacts immediately after the impact of the energy company's stock price in phase 1, and reaches its peak in Phase 5. After phase 5, the carbon risks start to decline and gradually tend to be stable. When energy companies were hit by carbon risks, they responded quickly in phase 1, and the trend continued to rise. The downward trend occurred in phase 5, and gradually stabilized after phase 6, indicating that the impact of carbon emission rights price on the share price of energy enterprises took a long time. When the carbon risks are impacted by the investor concerns, they react quickly and reach their peak in phase 1. As the sharp increase in the investor concerns will cause significant short-term impact on the carbon risks, other factors together cause a gradual decrease after phase 2 and a continuous upward trend from phase 5. After the energy company's stock price was impacted by the investor concerns, it began to continue to rise in the first phase. This is because the investor concerns reflect the investors' decision preference, which directly affects the energy company's stock price.

To sum up, the changes in energy companies' share prices are closely related to the fluctuations in carbon risks and investor concerns, as well as their own fluctuations. However, on the whole, the impact of carbon risks on energy companies' share prices is more volatile.

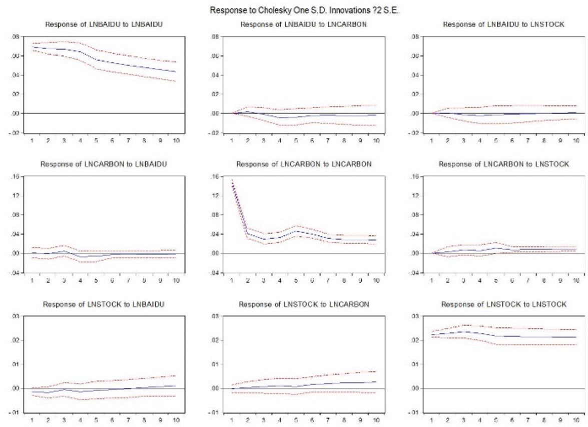

Fig 2. Impulse Response Results

4.1.8 Variance Decomposition

The analysis of variance decomposition is carried out on the share price of energy enterprises. From Table 6, it can be seen that the contribution of carbon risks to the share price of energy companies has been on a steady upward trend since the first lag phase, ranging from 1 to 10.

Table 6. Variance Decomposition Results

Number of phases	Standard error	LNSTOCK	LNCARBON	OIL	COAL	BTR	LNBAIDU
1	0.022416	99.58751	0.011062	0	0	0	0.385497
2	0.03203	99.4839	0.01641	2.694321	0.11214	0.059817	0.460152
3	0.039761	99.61049	0.045164	3.708706	0.385362	0.117491	0.30997
4	0.045865	99.55486	0.083828	3.655407	1.550681	0.172618	0.321856
5	0.050754	99.59201	0.084549	3.573224	2.362657	0.232845	0.282928
6	0.055151	99.56738	0.150844	3.5832	2.919749	0.296103	0.243609
7	0.059187	99.51533	0.239051	3.650151	3.302463	0.380177	0.212242
8	0.062963	99.44343	0.335859	3.730107	3.557193	0.485194	0.191591
9	0.066516	99.3628	0.428613	3.845173	3.747266	0.565373	0.181967
10	0.069887	99.26365	0.527195	3.962204	3.888859	0.627995	0.182174

4.2 Empirical Analysis based on the Intermediary Effect Model

4.2.1 The Construction of Intermediary Effect Model

In order to explore the impact path of carbon risks on energy companies' stock prices, this paper uses investor concerns as an intermediary variable to analyze the intermediary effect. The specific model is:

$$Y=a_0+a_1X+e_1 \tag{2}$$

$$Z=b_0+b_1X+M_1 \tag{3}$$

$$Y=c_0+c_1X+c_2Z+\xi_1 \tag{4}$$

Where Y represents the share price of an energy company, X represents the carbon risks, and Z represents the investor concerns.

4.2.2 The Estimation Results of the Intermediary Effect Model

The estimated results of the intermediary effect model constructed in this paper are shown in Table 7. The estimation results of formula (2) show that carbon risks are positively correlated to the energy company's stock price at a 5% confidence level, i.e., carbon risks have a positive promoting effect on the energy company's stock price. The estimation results of formula (3) show that carbon risks have a positive impact on investor concerns, but this impact is not significant. The estimation results of formula (4) show that both carbon risks and investor concerns have significant positive effects on the stock price of energy companies.

Whether there is an intermediary effect of investor concerns on the impact of carbon risks on energy companies' stock prices still needs to be determined by Sobel test. The Sobel test needs to first calculate the standard errors Sb1 and Sc2 of the statistical values Q, B1 and C2, and then judge by their corresponding p values. In this paper, Q= b1c2/s, s= $\sqrt{b_1^2 s_{c2}^2 + c_2^2 s_{b1}^2}$, Q value is -2.147, p value is 0.0469, less than 0.05, so the intermediary effect is established, indicating that carbon risks have a significant impact on energy companies' stock prices, and this impact is generated through the intermediary effect of investor concerns.

Table 7. Estimation of Mediating Effect Model

Explained variable					
dlnstock		lnbaidu		dlnstock	
(2)		(3)		(4)	
Explanatory variable	Estimation factor (p value)	**Explanatory variable**	Estimation factor (p value)	**Explanatory variable**	Estimation factor (p value)
lncarbon	0.038**(0.016)	lncarbon	0.097**(0.095)	lncarbon	0.014***(0.003)
Sobel test	-2.147				
p value	0.0469**				

Note: * * indicates rejection of the original assumption at the level of 5%.

5. Conclusion

Based on the daily data of energy companies' closing price and trading price of carbon emission rights from June 26, 2019 to November 7, 2022, and the official website data of Baidu Index, this paper constructs a VAR model among energy companies' share price and carbon risks, as well as investor concerns. The results show that there is an interactive relationship between energy companies' stock price and carbon risks. In addition, through impulse response, we find that the fluctuation of energy companies' share price is closely related to the fluctuation of carbon risks. Finally, this paper establishes an intermediary effect model, and finds that carbon risks have a significant impact on energy companies' stock prices, and this impact is generated through the intermediary effect of investor concerns.

In view of this, the paper puts forward the following suggestions: First, investors should be fully aware of the importance of reducing irrational investment in asset investment. Secondly, energy enterprises should vigorously promote technological innovation in order to realize the rapid development of energy transformation. Finally, give full play to the government's important role in the construction of the carbon trading market, and scientifically set carbon quotas to improve the efficiency of social resources allocation.

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