Risk Spillover Effects of International Risk Factors on China's Energy Market - Based on Geopolitical Threats and Shipping Markets

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Abstract

Risks caused by geo-risk cases, such as regional conflicts, propagate around the world, and this study provides insights into the dynamic and complex interactions of risks between international geopolitical risks, international shipping markets, China's carbon market, and the energy sector. The findings show that international geopolitical risk and international shipping markets are net transmitters of risk with positive net spillover values, indicating that they tend to export risk volatility to other markets. In contrast, the Chinese carbon market and the markets of traditional energy and high-emission sectors exhibit amplified volatility in the face of extreme risk events such as the COVID-19 pandemic, the Russian-Ukrainian conflict and the Israeli-Palestinian conflict. This highlights the time-varying nature of risk spillovers in these markets. Notably, the peaks in net spillovers from the Geopolitical Risk Index to the Baltic Dry Index and Shanghai crude oil futures suggest a direct correlation with geopolitical tensions affecting the oil and shipping industries, such as conflicts in oil-rich regions or maritime disputes affecting shipping lanes. These findings highlight the mediating role of international shipping in the transmission of geopolitical risks to regional markets. The paper concludes with policy recommendations for predicting and mitigating the impact of geopolitical uncertainty and shipping markets on energy markets.

1 Introduction

As the global climate change problem is becoming more and more prominent, countries have been strengthening the control and reduction of carbon emissions and promoting the development of renewable energy to cope with environmental challenges and energy security risks. China, as one of the world's largest greenhouse gas emitters, is also facing tremendous pressure and challenges (Chen et al. 2016). Against this backdrop, the Chinese government has actively responded to global climate governance initiatives, continuously promoting the construction of the carbon market and strengthening the regulation of traditional energy futures markets, while strongly supporting the development of the renewable energy industry. As the world's second largest economy and one of the largest carbon emitters, the development of China's energy market has an important impact on the global energy landscape. Against the backdrop of increasingly severe global climate change, the Chinese government has responded positively to the international community's call for greater control of carbon emissions and is committed to promoting the development of clean energy. China's carbon market, traditional energy futures market and renewable energy stock market, as an important part of China's energy market, have been directly affected by international factors (Kong et al. 2020).

China's carbon market is a national-level carbon trading mechanism, aiming to regulate carbon emissions and promote the development of a low-carbon economy through market mechanisms (Deng and Zhang 2019a). However, China's carbon market is still in its infancy and faces many challenges, among which the influence of international factors is particularly prominent. The fluctuations in the Geopolitical Risk Index, an important indicator of international political risk, may directly affect the supply and demand pattern of the global energy market, which in turn will have an impact on China's carbon market.
Meanwhile, fluctuations in the international shipping market may also affect China's carbon market, especially in the international trading of carbon emission rights, where fluctuations in shipping costs may affect carbon market prices and trading volumes (Deng and Zhang 2019b).

In addition to the carbon market, China's traditional energy futures market is also attracting attention (Han et al. 2016). China's crude oil futures and coke futures markets, as an important part of China's energy market, are characterized by price volatility that directly affects the profitability and market competitiveness of China's energy industry. International factors such as geopolitical risks and fluctuations in the international shipping market will have a direct impact on China's crude oil and coke import prices, which in turn will affect the price movements in the crude oil futures and coke futures markets (Gu et al. 2020). On the other hand, China's renewable energy market is also showing a booming development. The Chinese government has introduced a series of policy measures to promote the development of renewable energy, especially in areas such as solar and wind energy, which have made significant progress. As an important indicator reflecting the development of China's renewable energy industry, the Renewable energy Sector Index has received extensive attention from domestic and international investors (Czech and Wielechowski 2021). Fluctuations in international factors will also have a direct impact on China's renewable energy market. For example, advances in international clean energy technology and changes in the international carbon emissions trading mechanism may affect the pace and direction of China's renewable energy industry (Lin and Zhu 2019).

International factors play a crucial role in the development of China's energy market (Kong 2011). The Geopolitical Risk Index is an important indicator of international political risk, which directly affects the supply and demand situation in the international energy market. For example, the escalation of international geopolitical tensions could lead to disruptions in international energy supply, which could affect the price and stability of China's energy market (Overland 2015). In addition, fluctuations in the international shipping market also have a direct impact on China's energy market. As one of the world's largest trading nations, China's energy imports and exports depend on the capacity and price conditions in the international shipping market. Therefore, fluctuations in the international shipping market not only affect China's foreign trade business but may also have a significant impact on China's energy market supply chain and price trends (Arigoni et al. 2017).

This study aims to explore the impact of international factors on China's carbon market, traditional energy futures market and renewable energy stock market, which covers factors such as geopolitical risk index and international shipping market. The Geopolitical Risk Index is an important indicator of international political risk, while the volatility of the international shipping market is directly related to China's import and export trade and has a significant impact on China's economy and energy market. This paper will analyze the correlation between these factors and China's carbon market, traditional energy futures market and renewable energy stock market, aiming to provide reference for risk management and policy making in China's energy market. Through in-depth study of the impact of international factors on China's energy market, it can not only help enterprises and investors better grasp market opportunities and risks, but also help the government formulate more scientific and effective
policies to promote the optimization of China's energy structure and sustainable development. Therefore, this study has important theoretical and practical significance.

2 Literature Review

2.1 Geopolitical Risk on Energy Markets

Extensive research has been conducted in academia to explore the relationship between geopolitical risk and various aspects of energy markets. These studies cover the impact of geopolitical events on energy commodity prices, volatility spillovers between the oil market and the stock market, and the impact of geopolitical risk uncertainty on the future volatility of oil (Yang et al. 2021; Jin et al. 2023; Hudecova and Rajcaniova 2023; Gu et al. 2023).

For example, Liu et al. (2019) investigated the role of geopolitical risk in predicting the volatility of the oil market using the GARCH-MIDAS model and found that geopolitical risk has a significant impact on oil market volatility and plays a positive role in economic returns. These findings suggest that oil market investors and government policymakers should pay more attention to extreme geo-events and severe geopolitical risks. On the other hand, a study by Mamman et al. (2024) found that global uncertainty and geopolitical risk have significant effects on international energy prices and estimated these effects through a logit model. Their results suggest that an increase in global uncertainty may reduce excessive price volatility, while unfavorable geopolitical risks may exacerbate price volatility in the market.

In terms of the relationship between geopolitical risks and international energy markets, Vetrova et al. (2023) examine the development of the Russian energy industry and the impact of geopolitical events on energy trade. They point out that the current uncertainty and price volatility in the energy market puts pressure on Russia's export revenues and climate agenda, and as a result, Russia needs to update its energy development strategy to adapt to the green energy transition challenges. Meanwhile, a study by Pata et al. (2023) found that COVID-19 and the Russia-Ukraine conflict had an impact on mineral prices, in particular, geopolitical risks associated with Russia increased the prices of all minerals except cobalt. These results suggest that the resolution of the Russia-Ukraine conflict is crucial for more efficient utilization of clean energy minerals.

As for the relationship between geopolitical risk and renewable energy, researchers have also explored it in depth. While Smales (2021) found that geopolitical risk has a significant impact on oil price and stock market volatility and oil price is more affected by geopolitical risk while there is a spillover effect on stock price. Alqahtani and Klein (2021), on the other hand, examined the impact of geopolitical risk on the stock market of the Gulf Cooperation Council, and found that only Qatar's stock market is affected by global geopolitical risk negatively, while other member countries show a strong resilience to risk. Sohag et al. (2022) examined the impact of geopolitical risk on green stocks and green bonds using a cross-sectional quantile and quantile approach, and found that all indicators of geopolitical risk, except geopolitical acts, have an impact on green investments.
In addition, other studies have examined the relationship between geopolitical risk and financial markets. Lu and Liu (2024) investigate the impact of a comprehensive geopolitical risk index on China's FDI exported to 154 host countries and find that geopolitical risk negatively affects FDI, especially in the energy sector. Hossain et al. found that the Russia-Ukraine conflict had a negative impact on the foreign exchange market and this adverse effect of geopolitical risk was more significant under some specific conditions. The study by Shahzad et al. (2023) noted that geopolitical risk and financial instability had a significant impact on the traditional non-renewable energy and precious metals markets, especially during the Russia-Ukraine conflict in 2022.

Finally, there are also studies that explore the role of geopolitical risk in environmental sustainability. a study by Ozkan et al. (2024) finds that geopolitical oil price uncertainty has a non-linear effect on clean energy stock prices, while economic policy uncertainty, gold and natural gas prices have a negative effect. These studies provide policy recommendations for renewable energy investments and guide investors to make better decisions under uncertainty and volatility.

### 2.2 International shipping markets on energy markets

There is relatively little research on the linkages between international shipping markets and energy-related markets, with most of the literature focusing on exploring the environmental impacts, economic significance and strategic responses involved in the maritime industry's efforts to reduce carbon emissions. In this area, Christodoulou et al. (2024) provide an in-depth analysis of the prospects and impacts of emissions trading in the shipping industry. Through a qualitative review of IMO and EU actions, as well as a SWOT analysis of the potential of an Emissions Trading System (ETS) for shipping, they conclude that an ETS for shipping is expected to promote investment in green technologies and thus reduce the carbon footprint. This demonstrates the potential role of environmental policies in driving the shipping industry in a more sustainable direction. Meanwhile, Meng et al. (2023) study used wavelet analysis and spillover index methodology to reveal the existence of long-term dependencies and informational linkages between carbon finance markets and shipping. This finding further highlights the strong link between the environmental and financial sectors in the sustainable development of the shipping industry. In contrast, Chang et al. (2023) used data from 2019 to 2021 to analyze the impact of COVID-19 on global shipping through stepwise regression, revealing changes in the influencing factors of the Baltic Dry Index (BDI) before and after the epidemic. The results of this study not only deepen the understanding of the impact mechanism of the epidemic on the shipping market, but also provide important insights for future responses to similar crises.

Therefore, in the current literature, we can observe the following main features: first, there is a lack of comprehensive analysis. Many studies focus on specific aspects of the relationship between geopolitical risks and energy markets, such as price volatility or supply chain disruptions, while failing to provide a more comprehensive analysis. Therefore, there is a need to consider different aspects of geopolitical risks and their impact on energy markets in an integrated manner to obtain a more comprehensive understanding. Second, the existing literature focuses on the environmental impacts associated with the maritime industry's efforts to reduce carbon emissions. While this is an important topic, it may have led to
an understudy of other geopolitical risks in relation to energy markets. Therefore, in future research, more attention needs to be paid to other aspects of the relationship between geopolitical risk and energy markets to develop a more comprehensive understanding. The possible contributions of this paper are, first, to provide a more comprehensive perspective by conducting an integrated analysis of geopolitical risk and energy markets in the study. Such an integrated analysis should consider various dimensions of geopolitical risks, including geopolitical threats, geopolitical actions, etc., and their impacts on different energy markets, including traditional energy, renewable energy, and carbon markets. Second, this paper introduces the shipping market factor to verify whether the shipping market is a mediator of the impact of international geopolitical risks on China's energy market. Finally, this paper uses the frontier TVP-VAR-DY model, which effectively avoids the loss of samples compared to the traditional DY spillover index for a smoother risk spillover index measurement.

3 Methodology

Among the modelling methods for measuring the time-varying characteristics of time series, the spillover index model with rolling window is one of the most widely used models. However, this model has some limitations, due to the need to set a rolling window, on the one hand, it will lead to the loss of a certain number of samples and the instability of the results under different rolling window lengths; on the other hand, due to the loss of samples, the model is not friendly to the measurement of a smaller number of samples. The TVP-VAR-DY model calculates the coefficients of the time-varying through the introduction of time-varying parameter method (TVP-VAR), variance covariance matrix to smooth the estimation of volatility spillover, solves the above problems (Adekoya et al. 2022).

First, a 1st order TVP-VAR model is constructed as:

$$\Delta x_t = \beta_t \Delta x_{t-1} + \epsilon_t \epsilon_t \sim N \left(0, \sum_t\right)$$  \hspace{1cm} (1)

$$\text{vec} (\beta_t) = \text{vec} (\beta_{t-1}) + \nu_t \nu_t \sim N \left(0, R_t\right)$$  \hspace{1cm} (2)

where $\Delta x_t, \Delta x_{t-1}$ and $\epsilon_t$ are $N \times 1$ dimensional vectors, $\beta_t$ and $\sum_t$ are $N \times N$ dimensional matrices, the parameters $\text{vec} (\beta_t)$ and $\nu_t$ are $N^2 \times 1$ dimensional vectors, and $R_t$ is an $N^2 \times N^2$ dimensional matrix.

Based on this modelling framework, the TVP-VAR (Time Varying Parameter-Stochastic Volatility-Vector Auto Regression) model can be transformed into the moving average form of its vectors (TVP-VMA) according to Wold's theorem and the variance shares can be normalised to obtain the normalised forecast error variance shares:
where \( \psi_h \) denotes the N*N moving average narrative matrix with lag order h, and \( \theta_{i,j}^g (H) \) denotes the share of the forecast error variance contribution of variable i to j.

NPDC can represent the risk spillover between market i and market j in pairs:

\[
NPDC_{i,j} (H) = \left( \frac{\xi_{ji,t} (H) - \xi_{ij,t} (H)}{\xi_{ij,t} (H)} \right) \times 100
\]

To further measure spillover between a market and other markets in the sample, the spillover index (TO), the spillover index (FEOM), the net spillover index (NET):

\[
\text{To } g_{i\rightarrow j} (H) = \frac{\sum_{j=1}^{N_i} \xi_{ji,t} - \xi_{ij,t,0}}{\sum_{j=1}^{N_i} \xi_{ij,t,0}} (H)
\]

\[
\text{From } g_{i\leftarrow j} (H) = \frac{\sum_{i=1}^{N_j} \xi_{ji,t} - \xi_{ij,t,0}}{\sum_{i=1}^{N_j} \xi_{ij,t,0}} (H)
\]

\[
\text{Net}_{i,t} = \text{To } g_{i\rightarrow j} (H) - \text{From } g_{i\leftarrow j} (H)
\]

4. Analysis of empirical results

4.1 Data Selection and Preprocessing

The article examines the relationship between international geopolitical risk, the shipping market, the Chinese carbon market, energy commodities, and the renewable energy industry by selecting representative market and price indices: first, the Geopolitical Risk Index (GPR) is used by Caldara and Iacoviello (2022) to explore the energy market’s exposure to geopolitical risk (the original data is obtained from https://www.matteoiacoviello.com/gpr.htm). Specifically, the GPR index is constructed based on the number of geopolitically related articles reported in 10 major international newspapers including a total of eight categories of events including war threats, peace threats, military buildup, nuclear threats, terrorist threats, war outbreaks, war escalation, and terrorist activities. Secondly, the International Dry Bulk Market Index (BDI) is chosen to measure the international shipping market in this paper. Finally, the article selects the national carbon emissions trading market (CEA) to represent China’s carbon market, and uses China’s crude oil futures price (SC), coking coal futures price (DCE), and the renewable energy industry index (CSI) to represent the traditional energy crude oil market, the coking coal market, and the renewable
energy market in the energy market, respectively. The data are from CSMAR and WIND databases. Since the price dates of each market index are not identical, the article screens each sample data to ensure the continuous consistency of each series. To ensure the smoothness of the sample data, the article performs first-order differencing on the prices and indices of each market and uses the logarithmic yield series for the study.

4.2 Static spillover results

The TVP-VAR-DY spillover index can estimate the static risk spillover in the study sample. The full sample static risk spillover effects are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>GPR</th>
<th>BDI</th>
<th>CEA</th>
<th>SC</th>
<th>DCE</th>
<th>CSI</th>
<th>FROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPR</td>
<td>97.7</td>
<td>0.5</td>
<td>0.9</td>
<td>0.2</td>
<td>0.1</td>
<td>0.5</td>
<td>2.3</td>
</tr>
<tr>
<td>BDI</td>
<td>1.7</td>
<td>90</td>
<td>1.5</td>
<td>2.9</td>
<td>1.5</td>
<td>2.3</td>
<td>10</td>
</tr>
<tr>
<td>CEA</td>
<td>4.1</td>
<td>2.8</td>
<td>88.2</td>
<td>1.8</td>
<td>1.4</td>
<td>1.7</td>
<td>11.8</td>
</tr>
<tr>
<td>SC</td>
<td>2.6</td>
<td>3.9</td>
<td>0.6</td>
<td>86.1</td>
<td>4.3</td>
<td>2.6</td>
<td>13.9</td>
</tr>
<tr>
<td>DCE</td>
<td>2.2</td>
<td>1.6</td>
<td>0.9</td>
<td>5</td>
<td>88.6</td>
<td>1.8</td>
<td>11.4</td>
</tr>
<tr>
<td>CSI</td>
<td>4.1</td>
<td>4.6</td>
<td>1.3</td>
<td>3.4</td>
<td>1.9</td>
<td>84.7</td>
<td>15.3</td>
</tr>
<tr>
<td>Contribution TO others</td>
<td>14.7</td>
<td>13.4</td>
<td>5.2</td>
<td>13.3</td>
<td>9.2</td>
<td>8.9</td>
<td>-</td>
</tr>
<tr>
<td>NET directional connectedness</td>
<td>12.4</td>
<td>3.5</td>
<td>-6.6</td>
<td>-0.6</td>
<td>-2.2</td>
<td>-6.4</td>
<td>-</td>
</tr>
</tbody>
</table>

The net risk spillover table captures the directional spillover of risk spillovers between the two markets, with the diagonal values representing the extent to which the lagged effect of a market affects that market. Not surprisingly, the internal effects of all variables are greater than 84%. Among them, the internal effect of GPR is 87.7%, indicating a strong autocorrelation. The off-diagonal values represent the magnitude of the spillover effect of the first row variables on the first column variables. The value of the spillover effect of geopolitical risk on the shipping market is 1.7%, while the value of the spillover effect of the shipping market on geopolitical risk is 0.5%. It can be seen that the spillover effect is transmitted between markets. In addition, the spillover effect value of geopolitical risk on other markets is 14.7 and the net spillover effect is positive, indicating that geopolitical risk is at the center of risk spillover in the sample market, and once risk volatility arises, it is easy to affect other markets through interconnections, which triggers risk contagion or even systemic risk. Finally, for the whole sample species, only geopolitical risk and international shipping market have positive net spillover values, suggesting that they may be the exporters of volatility impacts and have a greater impact on other markets.

4.2 Analysis of Dynamic Aggregate Spillovers
Since the static volatility spillover estimates cannot reflect the spillover effects that vary over time, the article will further analyze the dynamic spillover effects. In fitting the time-varying spillover index, firstly, the article selects the model fitting lag order of 2 according to the AIC criterion and sets the forecasting step $H = 10$. The spillover effect index reflects the overall correlation of volatility between markets. The higher the index, the stronger the spillover effect between markets, and the easier it is for volatility changes in one market to be transmitted to other markets. The results of the total risk spillover index between China's carbon market, energy market and high-emission sector market are shown in Fig. 1.

Figure 1 reflects the trend in the total risk spillover index between July 19, 2021 and the end of March 2024 for the sample markets. Overall, the volatility of the total risk spillover index between the sample markets generally ranges from 5–10%. In a few cases peaks can reach around 53%. This shows that there is a time-varying feature in the total spillover between geopolitical risk, shipping market, China carbon market, energy commodities and renewable energy sector.

Specifically, there is a significant peak in the total spillover index from 2021, and the total risk spillover index peaks rapidly in a short period of time since the market launch of the national carbon market in 2021. On the one hand, this may be due to the access of the national carbon market, which has impacted the related industries of energy in China. On the other hand, this situation in 2021 due to the epidemic may have led to a high market sensitivity to geopolitical risks and high energy prices. As a result, it led to a sharp rise in the sample total risk spillover index during this period.

Thereafter, in early 2022, the total risk spillover index started to show an upward trend again. The reason for this should be twofold. On the one hand, the impact of the continuous increase in energy prices during the epidemic and the increase in energy demand as the society resumes production. On the other hand, the outbreak of war conflict between Russia and Ukraine at the beginning of 2022, as the world's major energy exporter, the conflict between Russia and Ukraine led to an increase in the geopolitical threat index and the total risk spillover effect of the international energy market. With a series of measures taken by the Chinese government to restore the economy and improve people's livelihoods, such as the temporary zero tax rate on coal imports and VAT exemption for small-scale taxpayers in response to the outbreak of the Russian-Ukrainian conflict, as well as the normalization of the new coronavirus outbreak, the risk is gradually declining, at which point the total risk spillover index begins to gradually stabilize. After October 2023, there is another peak in the total risk effect, which may be due to the geopolitical conflict of the Israeli-Palestinian conflict and the subsequent economic sanctions, international policy changes, and other related events. In summary, the article finds that risk spillovers between the shipping market, China's carbon market, energy commodities, and the renewable energy sector increase significantly in the event of major socio-economic events and extreme risk events.

### 4.3 Analysis of dynamic directional spillover effects

The total volatility spillover index can only capture the time-varying spillover effects of multiple markets in aggregate, and the article will further analyze the time-varying spillover effects between each market in the sample. The spillover index indicates the extent to which a market spills over to the volatility of other
markets, and the spillover index indicates the extent to which a market is affected by the spillover effects of other markets. Figure 3 shows the risk spillover and spillover effects as well as the net spillover effects for each market in the sample. The red line indicates the risk spillover effect of that market to other markets, the blue line indicates the risk spillover effect of other markets to that market, and the black line indicates the net spillover effect of the market.

Overall, first, the directional spillover index counteracts the time-varying nature of spillovers between markets. Second, the results of the directional spillover index show that the overall trend of spillovers and spillover indices is roughly the same across markets, with variations typically ranging from 1–20%. Specifically, for the geopolitical risk index charts show that spillovers to other markets were very high at the beginning of the period and then sharply weakened and stabilized. The initial high spillover may be related to the geopolitical events of the Russia-Ukraine conflict. The rapid decline in spillovers may indicate that while the initial shockwaves sent ripples through various markets, these markets quickly adapted to the new status quo. Spillovers from all other markets to the Geopolitical Risk Index have been low, implying that the Geopolitical Risk Index has always played the role of a risk transmitter rather than a receiver. The Baltic Dry Index (BDI) measures shipping costs and is generally a good proxy for global economic activity. In early 2021, the BDI reached a pronounced peak, which may have been associated with disruptions in global trade or higher commodity prices. Subsequent declines and stabilization may reflect a normalization of shipping rates as supply chains adjust in the wake of COVID-19. The spillover and net effect of other markets on the Baltic Dry Index was close to zero for most of the period, suggesting that the Baltic Dry Index was little affected by spillovers from other markets. The BDI appears to be more influenced by direct supply and demand factors within the shipping industry. The directional spillover of Chinese emission allowances started with a significant positive spike from the market to other markets and a less pronounced but still positive spike from other markets to the market. The initial surge may be related to the launch of China's national carbon market or regulatory changes affecting carbon pricing. The decline to more stable levels may indicate the expected integration of the carbon market into other markets. The net spillover of China's emission allowances has seen some volatility but remains slightly negative overall, suggesting it is more of a risk taker than a risk transmitter to other markets. Shanghai crude oil futures show a stable level of spillover to and from other markets, with net spillover hovering around zero. This equilibrium can be disturbed by major events in the oil market, such as an OPEC+ production cut resolution, a major change in production levels, or a geopolitical event that affects oil supply. The peaks and troughs of the net spillover may correspond to such events and investors in other markets may react to changes in oil prices. Net spillover in Dalian coking coal futures is usually close to zero, suggesting that the market is balanced between being a sender and receiver of risk. Occasional spikes may be in response to specific regulatory changes or market disturbances. The Renewable energy Index initially has a significant positive spillover effect on other markets, but quickly levels off. This initial spike may be related to policy announcements promoting renewable energy, technological breakthroughs or large investment flows into the renewable energy sector. The spillover from other markets to the CSI Renewable energy Index is not as significant, but shows a similar downward trend and stabilizes over time. The net spillover is relatively balanced with a
slightly negative trend, suggesting that the renewable energy sector absorbs more risk from other markets than it passes on, possibly due to the sector's growth potential and sensitivity to policy changes.

Due to the two-way nature of spillover effects, a higher spillover index only indicates greater correlation between markets and does not imply that the market has a net risk spillover relative to other markets. Therefore, further analysis through the net pairwise spillover index is still required to determine the dynamic linkages of market risk spillovers in specific cases.

4.4 Analysis of dynamic net pairwise spillover effects

The paired net spillover indices in Fig. 5 provide a concrete picture of the net spillover effect over time between the two markets in the sample. As shown in Fig. 5, it can be seen that the spillover index varies between positive and negative across markets, suggesting that there may be long-term two-way time-varying asymmetric spillovers between markets, with the magnitude and even the direction of the net spillover index suddenly and drastically changing at certain points in time. Specifically, the most prominent spikes observed in the charts of the Geopolitical Risk Index versus the other indices, particularly the sharp spike around the beginning of 2021, suggest that there are specific events that give rise to significant geopolitical risks that may lead to increased volatility in the affected markets. For example, spikes in the geopolitical risk index in relation to the Baltic Dry Index and Shanghai crude oil futures could be linked to geopolitical tensions that have a direct impact on oil and shipping markets, such as conflicts in oil-rich regions or maritime disputes affecting shipping routes. Notably, the net spillover peaks from the Geopolitical Risk Index to China Emission Allowances (CEA) and Dalian Coking Coal Futures (DCE) are not significant, suggesting that while geopolitical risks can affect these markets, their impacts may be more buffering or indirect. In the case of the BDI, the sharp spike in early 2021 may reflect the impact of pandemic-induced disruptions to global trade, which have caused significant volatility in shipping costs. These disruptions could include the blockage of the Suez Canal in March 2021, which had a dramatic impact on shipping and would lead to a spike in the net spillover of the BDI to other markets, particularly Shanghai crude oil futures and Dalian coking coal futures, which rely heavily on shipping logistics. Shanghai crude oil futures show a large net spillover around early 2021, which could be related to the volatility of global oil prices due to production cuts or demand shocks when the world economy is in trouble due to COVID-19. The net spillover between Dalian coking coal futures and CSI renewable energy has increased at different times, which may be due to the growing maturity of the renewable energy sector as a function of coal substitutes.

In summary, the article finds that, first, there is a certain degree of linkage between geopolitical risk and various markets, and that spillovers between markets are heterogeneous and asymmetric, for example, geopolitical risk is a risk exporter in the sample, while carbon and energy markets are risk receivers. Second, the article also finds that extreme risk events (for example, COVID-19 Russian-Ukrainian conflict, Palestinian-Israeli conflict) lead to a significant increase in the intensity of volatility spillovers between markets. Finally, the article finds that geopolitical risk can represent some of the major socio-economic and extreme risk events, resulting in absolute net risk spillovers to other markets in the sample. The shipping market, on the other hand, is essentially only affected by geopolitical risk in the sample, while
there is a significant risk spillover to other energy markets, especially the coke market, which may reflect the fact that the shipping market is an intermediary in the transmission of risk from international geopolitical risk to regional markets.

Overall, first, the directional spillover index counteracts the time-varying nature of spillovers between markets. Second, the results of the directional spillover index show that the overall trend of spillovers and spillover indices is roughly the same across markets, with variations typically ranging from 1% to 20%. Specifically, for the geopolitical risk index charts show that spillovers to other markets were very high at the beginning of the period and then sharply weakened and stabilized. The initial high spillover may be related to the geopolitical events of the Russia-Ukraine conflict. The rapid decline in spillovers may indicate that while the initial shockwaves sent ripples through various markets, these markets quickly adapted to the new status quo. Spillovers from all other markets to the Geopolitical Risk Index have been low, implying that the Geopolitical Risk Index has always played the role of a risk transmitter rather than a receiver. The Baltic Dry Index (BDI) measures shipping costs and is generally a good proxy for global economic activity. In early 2021, the BDI reached a pronounced peak, which may have been associated with disruptions in global trade or higher commodity prices. Subsequent declines and stabilization may reflect a normalization of shipping rates as supply chains adjust in the wake of COVID-19. The spillover and net effect of other markets on the Baltic Dry Index was close to zero for most of the period, suggesting that the Baltic Dry Index was little affected by spillovers from other markets. The BDI appears to be more influenced by direct supply and demand factors within the shipping industry. The directional spillover of Chinese emission allowances started with a significant positive spike from the market to other markets and a less pronounced but still positive spike from other markets to the market. The initial surge may be related to the launch of China's national carbon market or regulatory changes affecting carbon pricing. The decline to more stable levels may indicate the expected integration of the carbon market into other markets. The net spillover of China's emission allowances has seen some volatility but remains slightly negative overall, suggesting it is more of a risk taker than a risk transmitter to other markets. Shanghai crude oil futures show a stable level of spillover to and from other markets, with net spillover hovering around zero. This equilibrium can be disturbed by major events in the oil market, such as an OPEC+ production cut resolution, a major change in production levels, or a geopolitical event that affects oil supply. The peaks and troughs of the net spillover may correspond to such events and investors in other markets may react to changes in oil prices. Net spillover in Dalian coking coal futures is usually close to zero, suggesting that the market is balanced between being a sender and receiver of risk. Occasional spikes may be in response to specific regulatory changes or market disturbances. The Renewable energy Index initially has a significant positive spillover effect on other markets, but quickly levels off. This initial spike may be related to policy announcements promoting renewable energy, technological breakthroughs or large investment flows into the renewable energy sector. The spillover from other markets to the CSI Renewable energy Index is not as significant, but shows a similar downward trend and stabilizes over time. The net spillover is relatively balanced with a slightly negative trend, suggesting that the renewable energy sector absorbs more risk from other markets than it passes on, possibly due to the sector's growth potential and sensitivity to policy changes.
Due to the two-way nature of spillover effects, a higher spillover index only indicates greater correlation between markets and does not imply that the market has a net risk spillover relative to other markets. Therefore, further analysis through the net pairwise spillover index is still required to determine the dynamic linkages of market risk spillovers in specific cases.

4.4 Analysis of dynamic net pairwise spillover effects

The paired net spillover indices in Figure 5 provide a concrete picture of the net spillover effect over time between the two markets in the sample. As shown in Figure 5, it can be seen that the spillover index varies between positive and negative across markets, suggesting that there may be long-term two-way time-varying asymmetric spillovers between markets, with the magnitude and even the direction of the net spillover index suddenly and drastically changing at certain points in time. Specifically, the most prominent spikes observed in the charts of the Geopolitical Risk Index versus the other indices, particularly the sharp spike around the beginning of 2021, suggest that there are specific events that give rise to significant geopolitical risks that may lead to increased volatility in the affected markets. For example, spikes in the geopolitical risk index in relation to the Baltic Dry Index and Shanghai crude oil futures could be linked to geopolitical tensions that have a direct impact on oil and shipping markets, such as conflicts in oil-rich regions or maritime disputes affecting shipping routes. Notably, the net spillover peaks from the Geopolitical Risk Index to China Emission Allowances (CEA) and Dalian Coking Coal Futures (DCE) are not significant, suggesting that while geopolitical risks can affect these markets, their impacts may be more buffering or indirect. In the case of the BDI, the sharp spike in early 2021 may reflect the impact of pandemic-induced disruptions to global trade, which have caused significant volatility in shipping costs. These disruptions could include the blockage of the Suez Canal in March 2021, which had a dramatic impact on shipping and would lead to a spike in the net spillover of the BDI to other markets, particularly Shanghai crude oil futures and Dalian coking coal futures, which rely heavily on shipping logistics. Shanghai crude oil futures show a large net spillover around early 2021, which could be related to the volatility of global oil prices due to production cuts or demand shocks when the world economy is in trouble due to COVID-19. The net spillover between Dalian coking coal futures and CSI renewable energy has increased at different times, which may be due to the growing maturity of the renewable energy sector as a function of coal substitutes.

In summary, the article finds that, first, there is a certain degree of linkage between geopolitical risk and various markets, and that spillovers between markets are heterogeneous and asymmetric, for example, geopolitical risk is a risk exporter in the sample, while carbon and energy markets are risk receivers. Second, the article also finds that extreme risk events (for example, COVID-19 Russian-Ukrainian conflict, Palestinian-Israeli conflict) lead to a significant increase in the intensity of volatility spillovers between markets. Finally, the article finds that geopolitical risk can represent some of the major socio-economic and extreme risk events, resulting in absolute net risk spillovers to other markets in the sample. The shipping market, on the other hand, is essentially only affected by geopolitical risk in the sample, while there is a significant risk spillover to other energy markets, especially the coke market, which may reflect
the fact that the shipping market is an intermediary in the transmission of risk from international geopolitical risk to regional markets.

5 Conclusions and policy suggestions

5.1 Conclusions

The conclusions of the article are as follows. First, there are dynamic bidirectional asymmetric spillovers between international geopolitical risk, international shipping market and China's carbon market, energy market and renewable energy sector market. According to the static spillover index, the net spillover values of geopolitical risk and international shipping market are positive, indicating that they are the exporters of the impact of risk volatility. Second, according to the gross spillover index, under the influence of extreme risk events (for example, COVID-19, Russia-Ukraine war, and Israeli-Palestinian conflict), the volatility spillovers in China's carbon market, energy market, and high-emission industry market are significantly enhanced, showing the time-varying characteristics of risk spillovers between markets. Finally, according to the Net Spillover Index and the Net Paired Spillover Index, the spike in the Geopolitical Risk Index with respect to the Baltic Dry Index and Shanghai Crude Oil Futures could be related to geopolitical tensions that have a direct impact on the oil and shipping markets, such as conflicts in oil-rich regions or maritime disputes that affect shipping routes. Geopolitical risks can represent some of the major socio-economic events and extreme risk events, thus providing an absolute net risk spillover to other markets in the sample. The shipping market, on the other hand, is essentially only affected by geopolitical risk in the sample, while there is a significant risk spillover to other energy markets, particularly the coke market, which may reflect the fact that the shipping market is an intermediary in the transmission of risk from international geopolitical risk to regional markets.

5.2 Policy suggestions

Given the empirical findings of the dynamic bidirectional asymmetric spillover effects between international geopolitical risk, the international shipping market, the Chinese carbon market, the traditional energy market and the renewable energy industry market, a series of policy recommendations can be put forward to effectively manage and utilize these relationships.

Starting with international geopolitical risks, it is clear that geopolitical tensions have a direct impact on global markets, especially shipping and energy markets. Governments and businesses must strengthen their geopolitical risk assessment capabilities. This can be achieved by establishing intelligence units specialized in analysing geopolitical developments. These units would inform strategic decision-making and contingency planning. In addition, geopolitical risk insurance products should be developed to provide a financial cushion against potential losses from political unrest or conflict. Investing in conflict resolution and international diplomacy is also crucial. Active participation in international forums aimed at reducing geopolitical tensions is crucial. Supporting international law and maritime dispute settlement mechanisms will also help stabilize international shipping markets, which are highly sensitive to geopolitical fluctuations.
For the international shipping market, policies should encourage the diversification of trade routes and the development of alternative transportation infrastructure. Digitalization efforts could make the industry more flexible and able to respond to sudden changes in trade flows due to geopolitical tensions. In addition, the industry should move in a more sustainable direction, in line with global decarbonization efforts, thereby reducing its vulnerability to fossil fuel market volatility.

China's carbon market faces a unique set of challenges and opportunities. The stability of the market is critical and therefore requires a consistent and transparent regulatory framework. The government should consider setting clear long-term guidelines so that market participants have the confidence to invest in carbon reduction projects and technologies. Improved liquidity through market-based risk management instruments, such as carbon derivatives, can enable better hedging strategies and reduce market vulnerability to sudden external shocks. In the case of traditional energy markets, diversification is key. By reducing dependence on any single energy source or supplier, markets can withstand volatility associated with geopolitical risks. In addition, there is a need to invest in energy infrastructure that can withstand disruptions. This includes not only physical infrastructure, but also market structures that can flexibly respond to changes in energy supply and demand. The renewable energy industry market represents the future of global energy consumption. Policymakers should create an enabling environment for its growth. This means not only incentivizing the development of renewable energy projects, but also ensuring that the market for these sources of energy is robust and can be integrated into existing energy grids. Supporting innovations in energy storage and smart grid technologies is crucial to address the intermittency of renewable energy sources.

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**Data Availability**
The datasets generated during and/or analysed during the current study are not publicly available due to part of the data is derived from non-free databases but are available from the corresponding author on reasonable request.

References

Figures

Figure 1

Aggregate risk spillover indices
Figure 2

Directional Spillover Index
Figure 3

Net Pairing Risk Spillover Index