

Risks in Cross-Border E-Commerce Supply Chains Due to the Interactive Impact of Geopolitical and Extreme Weather Factors: A Basic Moderating Effect Model

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Abstract. This study examines the impact of geopolitical and extreme weather threats on vulnerabilities within cross-border e-commerce supply chains, employing structural equation modeling for analysis. Data were collected using a questionnaire survey, primarily from Chinese cross-border e-commerce firms in 2025. The research identified 23 observed indicators across three dimensions: geopolitical risks, extreme weather risks, and cross-border e-commerce supply chain risks, assessed utilizing a 7-point Likert scale. Empirical evidence indicates that geopolitical risk and extreme weather risk substantially increase the risk associated with cross-border e-commerce supply chains. Furthermore, extreme weather risk substantially influences the correlation between geopolitical risk and cross-border e-commerce supply chain risk. When the likelihood of extreme weather is low, the impact of geopolitical risk on supply chain risk has an inverse link. Moreover, three explanations for this phenomenon are proposed: the cross-border e-commerce industry possesses strong adaptability, market stability, and China's irreplaceable role as a manufacturer. This paper provides theoretical frameworks and practical insights for risk management in cross-border e-commerce supply chains.

Keywords: Cross-Border e-commerce supply chains risks, Moderating effect, Geopolitical risks, Extreme weather risks

1. Introduction

By 2025, it is projected that geopolitical tensions, including trade sanctions and regional conflicts, in conjunction with climate change factors, such as extreme weather and carbon emission regulations, will progressively exert an influence on global supply chains [1]. The occurrence of recurrent natural disasters, occasioned by climate change, compounded by tariff barriers or shipping disruptions emanating from geopolitical tensions, poses unprecedented challenges to the stability of cross-border logistics networks for e-commerce. This study builds upon extant research on the individual impacts of extreme weather and geopolitics on global supply chains. It investigates the potential moderating impact of sporadic short-term extreme weather events on cross-border e-commerce supply chain risks. It considers the prolonged influence of geopolitical factors amid escalating geopolitical conflicts by 2025. The data collection employed a 7-point Likert scale

questionnaire survey method, and structural equation modelling was utilised to analyse the relationships among geopolitics, climate change, their moderating effects, and cross-border e-commerce supply chain risks. This study elucidates the intricate interplay between geopolitics and climate change, demonstrating their collective impact on supply chain logistics risks. It thereby addresses a theoretical deficiency in the literature, which primarily emphasizes isolated risk factors. In light of the escalating geopolitical tensions and the increasing prevalence of extreme weather events, this framework aims to enhance the comprehension of multidimensional risk interactions and to provide pragmatic risk management insights for cross-border e-commerce businesses. In view of the geopolitical tensions and recurrent extreme weather events, businesses can refine their supply chain design, bolster the resilience of their logistics networks, and formulate more effective risk response strategies informed by this research.

2. Literature review

2.1. Existing research and research gaps

Geopolitical risks refer to potential threats arising from political, military, economic, or social conflicts, policy shifts, or instability between nations or regions, which may impact investments, market operations, or international relations [2]. Specific manifestations include warfare, terrorism, trade sanctions, diplomatic tensions, regime change, or policy uncertainty. These risks are typically sudden and unpredictable, exerting significant influence on economic actors' decision-making and the global market environment. Extreme weather risks refer to potential threats triggered by abnormal or extreme weather events (such as hurricanes, floods, droughts, extreme heatwaves, or cold snaps), which may cause significant damage to human life, infrastructure, economic activities, and the ecological environment [3]. Supply Chain Risks refers to the potential risk of disruption or loss during supply chain operations caused by external or internal factors, which may affect the flow of goods, services, or information [4].

Existing literature predominantly focuses on traditional risks (e.g., studies on impacts of logistics delays and tariffs) or single-dimensional risks (e.g., studies on economic and legal risks) [5,6]. While the individual impacts of extreme weather and geopolitics on global supply chains have been examined, the interactive effects of geopolitics and climate change as dynamic drivers of cross-border e-commerce supply chain risks remain understudied [7,8].

2.2. Research hypotheses

Research indicates that both geopolitics and climate change are significant drivers of supply chain risks [9]. Geopolitics directly impacts supply chain stability through trade barriers, shipping restrictions, or regional conflicts, such as increased tariff costs or disrupted shipping routes. Therefore, this study proposes the following hypothesis:

H1: Geopolitics exerts a significant positive influence on logistics risks within cross-border e-commerce supply chains.

As an environmental factor, extreme weather further exacerbates supply chain risks by damaging logistics infrastructure or prolonging transportation times [10]. Therefore, this study proposes the following hypothesis:

H2: Extreme weather has a significant positive impact on logistics risks in cross-border e-commerce supply chains.

This paper proposes that extreme weather may amplify or mitigate the impact of geopolitics on cross-border e-commerce supply chain risks through a moderating effect. For instance, when geopolitical tensions restrict shipping routes, extreme weather may further degrade logistics efficiency, thereby intensifying risks. Based on the above definitions and relationship analysis, the following hypothesis is proposed:

H3: Extreme weather significantly moderates the relationship between geopolitical factors and logistics risks in cross-border e-commerce supply chains.

3. Research methodology

3.1. Data collection

This study employed a questionnaire survey methodology for data acquisition. The dissemination of the questionnaire and the data collection adhered rigorously to ethical standards and scientific protocols. Surveys were sent and gathered via online channels. Prior to participation, all respondents received a detailed research information paper defining the study's aims, substance, and promises to data confidentiality. Participation was entirely voluntary. This study has particular restrictions in data collection, as respondents were primarily located in the provinces of Guangdong, Zhejiang, Jiangsu, and Hebei areas where Chinese cross-border e-commerce firms and their supply chain organizations are generally found. Nonetheless, specific regions continue to lack representation. The questionnaire comprised two main sections: One is basic demographic information, including age, gender, years of experience in the cross-border e-commerce industry, and company size; Another is 23 observational indicators constructed around three key dimensions: geopolitical risks, extreme weather risks, and supply chain risks. These indicators were derived from observational variables and established scales in relevant literature, as shown in Table 1. Responses were scored using a 7-point Likert scale. A total of 260 questionnaires were distributed, yielding 255 valid responses—a response rate of 98.1%. Analysis of basic demographic information is presented in Table 2.

Table 1. Scale composition

Factor name	Observed variable
Geopolitical risk [11]	Political instability
	Trade dispute risk
	Regulatory change risk
	Supply chain disruption risk
	Cybersecurity risks
	Risk of economic recession
	Geopolitical tension risk
Extreme weather risks [7]	Probability of disaster occurrence
	Exposure level
	Vulnerability index
	Duration of disruption
	Economic impact
	Adaptive capacity
Cross-border e-commerce supply chain risks [9]	Market information misjudgment risk
	Information distortion risk
	Information security risks
	Risk of delayed Information-sharing
	Policy control risk
	Weather disaster risk
	Logistics management system instability risk
	Customs clearance risk
	Cash flow risk
	Supply chain performance

Table 2. Frequency analysis results

Name	Option	Frequency	Percentage (%)	Cumulative percentage(%)
1. Your gender is	Male	122	47.84	47.84
	Female	133	52.16	100
2. How many years of experience do you have in the cross-border e-commerce industry?	1~3Years	28	10.98	10.98
	4~6Years	78	30.59	41.57
	7~10Years	94	36.86	78.43
	11~15Years	42	16.47	94.9
	Above 15Years	13	5.1	100
	Microenterprises(<50 employees)	18	7.06	7.06
3. What is the size of your company?	Medium-sized enterprises(51~250 employees)	74	29.02	36.08
	Medium-to-large enterprises(251~1000 employees)	123	48.24	84.31
	large enterprises(>1000 employees)	40	15.69	100
	B2C	115	45.1	45.1
4. What is the primary business type of your company?	B2B	68	26.67	71.76
	Both	72	28.24	100
Total		255	100	100

3.2. Selection and model construction

Latent variables and observable variables are two fundamental components in structural equation modeling. Latent variables are not directly observable and necessitate observed variables for their measurement. In the analysis, observable variables quantitatively represent the magnitude of latent variables. Table 1 illustrates that geopolitical events, harsh weather, and disruptions in cross-border e-commerce supply chains are regarded as latent variables. Each factor is further categorized into: disruption duration, economic impact, adaptability, risk of misinterpreting market information, risk of information distortion, information security risk, risk of delayed information dissemination, regulatory policy risk, meteorological disaster risk, logistics management system instability risk, customs clearance risk, capital flow risk, and supply chain performance. The outcomes for the observed variables were obtained by the analysis of data gathered from questionnaires.

Structural equation modelling (SEM) is a complex framework designed to examine relationships among latent variables while describing the pathways through which these variables interact. This approach not only analyzes which explanatory variables influence others but also explores the mechanisms or pathways through which such influences occur. Furthermore, it enables the assessment of the multifaceted and context-dependent nature of these effects. Building upon the preceding section, structural equation modelling is conducted. Hypothesis H1 posits that geopolitical factors (GEO) exert a positive influence on cross-border e-commerce supply chain risks (EBSCR). Similarly, Hypothesis H2 suggests that extreme weather events (WEA) exert a positive influence on cross-border e-commerce supply chain risks (EBSCR). Hypothesis H3 posits that Extreme weather acts as a moderator variable, regulating the extent of GEO's influence on EBSCR. In this process,

the interaction between GEO and WEA generates the interaction term $WEA \times GEO$, reflecting the combined effect. The structural path is illustrated in Figure 1.

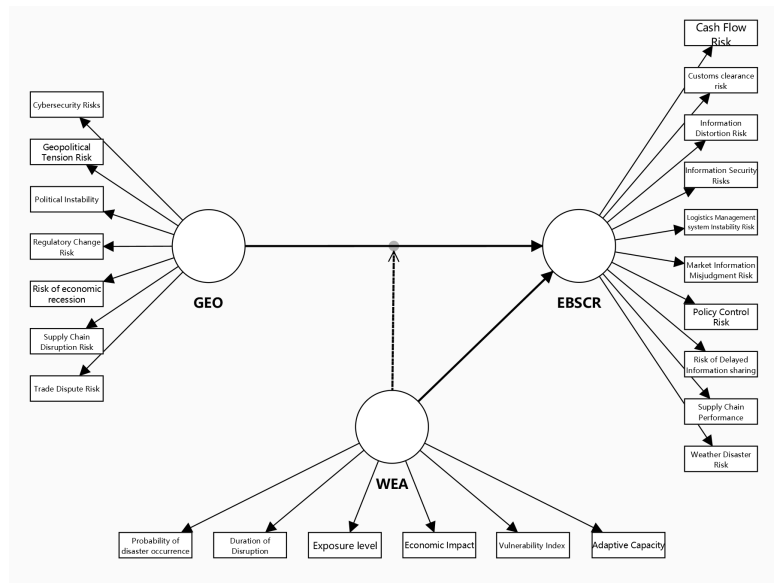


Figure 1. Structural path (picture credit : original)

4. Empirical findings

4.1. Sample reliability test

4.1.1. Reliability testing

To assess the internal consistency reliability of the scale, this study calculated Cronbach's α coefficients for each latent variable. According to the literature, Cronbach's α coefficients greater than 0.7 are generally considered to indicate good reliability [12]. Results show that Cronbach's α coefficients for all latent variables reached or exceeded 0.9, indicating high internal consistency reliability of the scale. To further validate the scale's reliability, this study calculated the composite reliability (CR) for each latent variable. A CR value above 0.7 typically indicates good composite reliability for latent variables [13]. Results showed that all latent variables had CR values exceeding 0.7, indicating high measurement reliability for the scale. Specific results are presented in Table 3.

Table 3. CR and AVE

	Cronbach's alpha	Composite reliability(rho_a)	Composite reliability(rho_c)	Average variance extracted(AVE)
EBSCR	0.932	0.936	0.942	0.621
GEO	0.922	0.926	0.937	0.68
WEA	0.901	0.903	0.924	0.669

To further validate the indicator reliability of the scale, this study examined the Outer loadings of each measurement indicator. According to Outer loadings greater than 0.7 indicate strong explanatory power of the indicator for the latent variable. Results show that most indicators had

outer loadings above 0.7, indicating overall good indicator reliability for the scale [12]. Specific results are presented in Table 4.

Table 4. Outer loadings

	EBSCR	GEO	WEA
Adaptive capacity			0.836
Cash flow risk	0.79		
Customs clearance risk	0.801		
Cybersecurity risks		0.813	
Duration of disruption			0.816
Economic impact			0.822
Exposure level			0.828
Geopolitical tension risk			0.803
Probability of disaster occurrence		0.821	
Information distortion risk	0.782		
Information security risks	0.752		
Logistics management system instability risk	0.762		
Market information misjudgment risk	0.797		
Policy control risk	0.803		
Political instability		0.849	
Regulatory change risk		0.821	
Risk of delayed information sharing	0.78		
Risk of economic recession		0.829	
Supply chain disruption risk		0.822	
Supply chain performance	0.815		
Trade dispute risk		0.818	
Vulnerability index			0.803
Weather disaster risk	0.795		

To detect potential multicollinearity issues in the scale, this study calculated the variance inflation factor (VIF) for each indicator. According to a VIF value below 3 indicates no severe multicollinearity problems [12]. Results show that all indicators' VIF values are below 3, indicating no significant multicollinearity issues in the scale, making it suitable for subsequent structural equation modelling analysis. Specific results are presented in Table 5.

Table 5. VIF

	VIF
Adaptive capacity	2.382
Cash flow risk	2.207
Customs clearance risk	2.378
Cybersecurity risks	2.539
Duration of disruption	2.189
Economic impact	2.141
Exposure level	2.307
Geopolitical tension risk	2.111
Probability of disaster occurrence	2.446
Information distortion risk	2.12
Information security risks	2.037
Logistics management system instability risk	2.094
Market information misjudgment risk	2.229
Policy control risk	2.268
Political instability	2.553
Regulatory change risk	2.286
Risk of delayed information sharing	2.219
Risk of economic recession	2.4
Supply chain disruption risk	2.323
Supply chain performance	2.459
Trade dispute risk	2.356
Vulnerability index	2.068
Weather disaster risk	2.221
WEA x GEO	1

4.1.2. Validity testing

To assess the convergent validity of the scale, this study calculated the average variance extracted (AVE) for each latent variable. Following the recommendation, an AVE value greater than 0.5 indicates that the latent variable adequately explains the variance of its indicators, demonstrating good convergent validity [13]. Results show that the AVE values for all latent variables exceeded 0.5, confirming the scale's strong convergent validity. Specific results are presented in Table 3. To assess discriminant validity, this study employed the HTMT (heterogeneity-to-monotonicity ratio) method. According to HTMT values below 0.85 (or below 0.9 under stricter conditions) indicate good discriminant validity between latent variables [14]. Results show that HTMT values for all latent variable pairs were below 0.85, confirming the scale's good discriminant validity. Specific results are presented in Table 6.

Table 6. HTMT values

	EBSCR	GEO	WEA
EBSCR			
GEO	0.341		
WEA	0.473	0.383	
WEA x GEO	0.328	0.255	0.162

4.2. Structural modelling analysis

Path relationships in the structural equation model were tested for significance using Bootstrap and two-tailed tests (significance level set at 0.05). Specific path analysis diagrams and coefficient significance are shown in Figure 2 and Table 7.

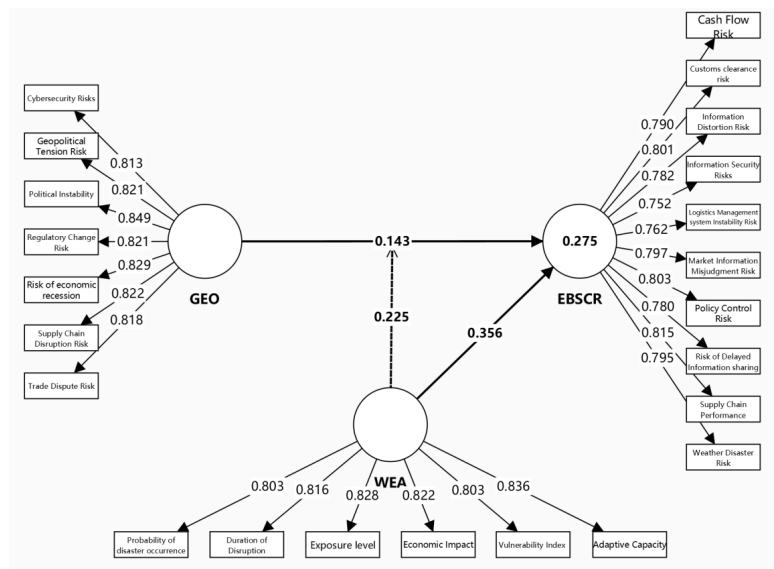


Figure 2. Path analysis diagram and path coefficients(picture credit : original)

Table 7. Path coefficient significance

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values
GEO -> EBSCR	0.143	0.149	0.052	2.733	0.006
WEA -> EBSCR	0.356	0.359	0.053	6.726	0

Findings demonstrate that geopolitical risks have a substantial beneficial impact on cross-border e-commerce supply chain risks, evidenced by a path coefficient of 0.143 ($P < 0.01$), hence validating hypothesis H1; Extreme weather has a substantial beneficial impact on cross-border e-commerce supply chain risks, evidenced by a path coefficient of 0.356 ($P < 0.01$), hence validating hypothesis H2;

This study assessed the predictive validity and explanatory strength of the structural equation model by Q^2 and f^2 tests (refer to Tables 8 and 9). The Q^2 value was initially computed employing

the blind prediction method to assess the model's predictive significance. A Q^2 value exceeding 0 signifies predictive importance, with thresholds of 0.02, 0.15, and 0.35 denoting low, medium, and high predictive relevance, respectively. The results indicate that the Q^2 values for all latent variables are larger than 0 and surpass 0.35, demonstrating significant predictive relevance of the model. The explanatory contribution of each exogenous latent variable to endogenous latent variables was evaluated using the effect size f^2 , with values of 0.02, 0.15, and 0.35 indicating small, medium, and high effect sizes, respectively. Results demonstrate that extreme weather has a moderate predictive capacity for the satisfaction component, whereas the predictive capacity of the interaction term between geopolitics and GEO-WEA is minimal.

Table 8. Q value

	SSO	Sum of squared errors (SSE)	$Q^2 (=1-SSE/SSO)$
EBSCR	2550	1441.43	0.435
GEO	1785	976.553	0.453
WEA	1530	866.65	0.434

Table 9. F statistic

	EBSCR
GEO	0.024
WEA	0.152
WEA x GEO	0.067

5. Analysis and discussion

5.1. Analysis of moderation effects

Moderation analysis investigates the interaction between independent variables and moderator variables concerning the dependent variable, assuming that both independent and dependent variables are preset. To assess the moderating influence of harsh weather on geopolitical risks and cross-border e-commerce supply chain hazards, a PLS-SEM analysis was performed in two stages: Step 1 evaluates the primary effects of the model, focusing on the correlation between each independent variable and the dependent variable without considering interaction effects; Step 2 investigates the interaction effect between the moderator and independent factors on the dependent variable. Previous findings indicate that geopolitical risks significantly enhance cross-border e-commerce supply chain risks (path coefficient: 0.143, $P < 0.01$), whereas extreme weather significantly exacerbates these risks (path coefficient: 0.356, $P < 0.01$). The analysis of their interaction (refer to Table 10) reveals that the path coefficient for "extreme weather $\times$ geopolitical risk" attained a significant level, signifying a beneficial moderating influence. The hypothesis H3 is corroborated.

Table 10. Path coefficient significance

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values
WEA x GEO -> EBSCR	0.225	0.222	0.049	4.617	0

To examine and quantify the strength and direction of the moderating variable's influence on the main effect relationship, this study employed a simple slope analysis using SmartPLS 4.0, with results presented in Figure 3. The figure reveals: When WEA is at +1 SD, GEO exhibits a positive correlation with EBSCR; When WEA is at the mean, GEO maintains a positive correlation with EBSCR, but the slope is significantly lower than when WEA is at +1 SD; When WEA is at -1 SD, GEO is negatively correlated with EBSCR. The slopes of the three lines are markedly different, indicating that GEO's influence on EBSCR varies with changes in WEA levels. This is a classic characteristic of a moderating effect.

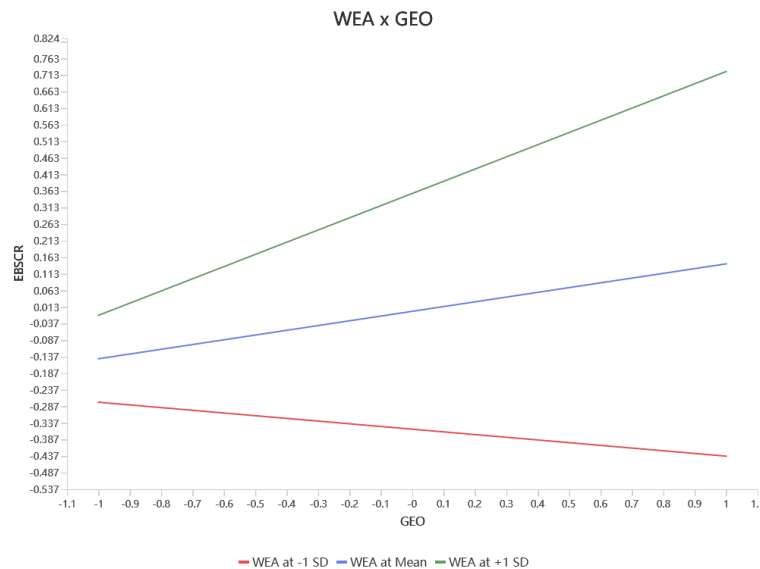


Figure 3. Slope analysis

6. Discussion of special points

6.1. Analysis of slope changes

It can be observed that when the moderator variable WEA is at a low level, it alters the direction of the independent variable GEO's effect on the dependent variable EBSCR. Analysis and interpretation follow.

The equation for the moderation effect is as follows:

$$Y=b_0+b_1X+b_2M+b_3(X\times M)+\epsilon \quad (1)$$

Y represents the dependent variable in this study, namely cross-border e-commerce supply chain risk; X denotes the independent variable, geopolitical factors; M signifies the moderating variable, extreme weather; $X\times M$ is the interaction term. b_1 , b_2 , and b_3 are the effect coefficients for the

independent variable, moderating variable, and interaction term, respectively. The slope of the independent variable X on the dependent variable Y can be derived by taking the partial derivative with respect to M, yielding the following equation:

$$\frac{\partial Y}{\partial X} = b_1 + b_3M \quad \frac{\partial X}{\partial Y} = b_1 + b_3M \quad (2)$$

It is evident that the slope is jointly determined by b_1 , b_3 , and the moderator variable M. As shown in Tables 7 and 10, $b_1 = 0.143$ and $b_3 = 0.225$. $b_3 > b_1$. Therefore, when M is at the 1SD level, b_3M is a large negative value, resulting in a negative final slope.

6.2. Discussion of causes

While it is scientifically established that increased geopolitical risks elevate overall supply chain risks when extreme weather risks are at average or higher levels, the observation that increased geopolitical risks reduce cross-border e-commerce supply chain risks when extreme weather risks are below average is an anomalous and noteworthy phenomenon. This study examines the interaction of these factors within the context of supply chain dynamics, aiming to provide insights into why increased geopolitical risks may mitigate certain risks in cross-border e-commerce supply chains under specific conditions (low WEA).

6.2.1. Strong adaptability of the cross-border e-commerce industry

In regions with below-average WEA (relatively stable climates), the risk of physical supply chain disruptions is lower. At such times, increased GEO (e.g., interregional trade restrictions or geopolitical conflicts) accelerates companies' efforts to diversify supply chains, seek alternative suppliers, or shift to more resilient logistics routes [15]. Mature enterprises directly mitigate risks by adjusting supply chain geography, such as relocating warehouses or selecting more stable transport routes. Such flexible adjustments are easier to implement when WEA is low, as the absence of extreme weather disturbances allows for greater redundancy and adaptability within logistics networks.

6.2.2. Stable market

This study focuses on China's cross-border e-commerce sector. Given China's status as the world's largest exporter, most cross-border e-commerce enterprises concentrate on export services. Global dumping means that escalating geopolitical risks in a single region impact overall export operations far less than losses from major domestic natural disasters [16]. In some real-world cases, such risks may not even affect sales volume. (e.g., following the 2025 U.S. tariff policy, many European and East Asian countries imported products previously purchased from the U.S. before tariff hikes and resold them to the U.S. to profit from the price differential; similarly, during the Russia-Ukraine conflict, Russia exported oil and natural gas banned by European countries to India, which then resold these resources to Europe).

6.2.3. China's irreplaceability as a manufacturer

This study focuses on China's cross-border e-commerce sector. Given China's status as the world's largest exporter, most cross-border e-commerce enterprises concentrate on export services. Global dumping means that escalating geopolitical risks in a single region impact overall export operations far less than losses from major domestic natural disasters [17]. In some real-world cases, such risks may not even affect sales volume. (e.g., following the 2025 U.S. tariff policy, many European and East Asian countries imported products previously purchased from the U.S. before tariff hikes and resold them to the U.S. to profit from the price differential).

7. Conclusion

This study develops and evaluates a moderation effect model that includes geopolitical risks, extreme weather, and their interaction terms to investigate their influence on the risks associated with China's cross-border e-commerce supply chain. The results indicate that both geopolitical threats and Extreme weather significantly raise cross-border e-commerce supply chain risks, with their interaction further intensifying these risks. Significantly, while extreme weather risks are minimal, heightened geopolitical threats may counterintuitively diminish supply chain risks, owing to the industry's robust adaptability and consistent market demand attributes.

This study presents significant conclusions regarding the interplay between geopolitical risk, extreme weather risk, and cross-border e-commerce supply chain risk; yet, it is not without limits. The geographical dispersion of data sources is limited. The questionnaire study largely targeted provinces with a high concentration of cross-border e-commerce firms, including Guangdong, Zhejiang, Jiangsu, and Hebei, excluding enterprises from other regions of China, particularly the central and western areas. This may limit the national representativeness of the results. The qualifications of the questionnaire respondents differed considerably. Although the sample comprised participants with diverse years of experience and from organizations of varying sizes, some respondents may have possessed insufficient comprehension of geopolitical or extreme weather concerns, potentially adding bias to their responses. Future studies should improve the universality and representativeness of findings while further investigating the linkages between various external or internal factors, such as digital transformation, policy stability, or changes in consumer behavior, as well as geopolitical and extreme weather threats. This would aid in the development of a more complete risk management framework for cross-border e-commerce supply chains.

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