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Supply Chain Resilience and Enhancement Paths of Cross-border E-commerce Export Empowered by Liaoning Ports under the RCEP Framework

Fenglin Yang[a], Lina Wang[b,*]

School of International Business, Liaoning Normal University, Dalian, 116000, China
[a]yangfenglin@lnnu.edu.cn, [b]wanglina@lnnu.edu.cn

Abstract: *The Regional Comprehensive Economic Partnership (RCEP) agreement has created unprecedented institutional opportunities for cross-border e-commerce (CBE) development in China's northeastern region. This study examines how Liaoning's port infrastructure empowers CBE export supply chain resilience under the RCEP framework, employing a mixed-methods approach combining panel data analysis of 120 CBE enterprises across Liaoning's seven comprehensive pilot zones from 2018 to 2024, with structural equation modeling and in-depth case studies. Our findings reveal that RCEP-driven port empowerment significantly enhances supply chain resilience ($\beta = 0.386$, $p < 0.01$), with supply chain integration serving as a critical mediation mechanism (Sobel $Z = 4.852$, $p < 0.01$). The heterogeneity analysis demonstrates that port empowerment effects are most pronounced in Dalian ($\beta = 0.452$) and Yingkou ($\beta = 0.381$) port areas, while inland ports exhibit moderate but statistically significant effects. Furthermore, the digital transformation of port operations and multimodal transport integration emerge as key moderating factors. Based on these findings, we propose a systematic enhancement framework encompassing institutional optimization, digital infrastructure upgrading, overseas warehouse network expansion, and talent cultivation. This research contributes to the theoretical understanding of port-CBE nexus in regional trade agreements and provides actionable policy recommendations for leveraging RCEP institutional dividends to strengthen northeastern China's digital trade competitiveness.*

Keywords: *RCEP; Cross-border e-commerce; Port empowerment; Supply chain resilience; Liaoning; Digital trade*

1. Introduction

Cross-border e-commerce (CBE) has emerged as a transformative force in global trade restructuring and digital economy development. In 2024, China's CBE import and export volume reached 2.63 trillion yuan, representing a year-on-year growth of 10.8% and accounting for 6% of total national goods trade (Ministry of Commerce, 2025). As the only coastal and border province in Northeast China, Liaoning Province recorded CBE transactions of 59.9 billion yuan in 2024, surging 23.4% year-on-year, while its trade with RCEP partners grew by 8.4% (Liaoning Provincial Government, 2025). These figures underscore CBE's role as a vital growth engine for Liaoning's foreign trade transformation.

The implementation of the Regional Comprehensive Economic Partnership (RCEP) since January 2022 has fundamentally altered the institutional landscape for regional digital trade. Beyond tariff concessions, RCEP encompasses provisions on rules of origin, customs procedures and trade facilitation, e-commerce, intellectual property rights, and SME cooperation (Ministry of Commerce, 2022). For CBE enterprises, these rules induce systemic changes across cost accounting, supply chain configuration, customs clearance, data compliance, and after-sales services. The agreement's cumulative rules of origin and streamlined customs procedures are particularly consequential for port-dependent CBE operations.

Liaoning possesses distinctive port infrastructure advantages, including Dalian International Shipping Hub, Yingkou Port, Dandong Port, and Shenyang International Dry Port, complemented by free trade zones and comprehensive CBE pilot areas. By 2025, Liaoning had established seven comprehensive CBE pilot zones across Shenyang, Dalian, Anshan, Fushun, Yingkou, Panjin, and Dandong (Liaoning Provincial Government, 2025). However, the quantitative expansion of open platforms does not automatically translate into competitive advantages. The core challenge lies in

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converting RCEP institutional dividends and port logistics capabilities into sustainable supply chain resilience—the capacity to prepare for, respond to, and recover from disruptive events while maintaining continuous operations (Ponomarov and Holcomb, 2009).

Despite growing scholarly attention to RCEP's economic impacts, existing literature exhibits three notable gaps. First, most studies focus on aggregate trade effects while neglecting the micro-level mechanisms through which port infrastructure empowers CBE supply chains. Second, the concept of supply chain resilience remains under-theorized in the context of regional trade agreements and digital trade platforms. Third, empirical research on Northeast China's CBE development is scarce, particularly regarding port-CBE nexus analysis. This study addresses these gaps by investigating how RCEP institutional arrangements and Liaoning's port infrastructure collectively shape CBE export supply chain resilience, and what enhancement paths can be formulated.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature and develops the theoretical foundation. Section 3 presents the conceptual framework and research hypotheses. Section 4 describes the research design and data sources. Section 5 reports empirical results. Section 6 discusses the findings, and Section 7 concludes with policy implications.

2. Literature Review and Theoretical Analysis

2.1 RCEP and Cross-border E-commerce Development

The academic discourse on RCEP's trade effects has expanded considerably since the agreement's ratification. Liu and Wang (2024) demonstrate that RCEP tariff concessions and trade facilitation measures significantly promote agricultural trade among member countries. Hou and Jie (2023) examine digital trade development levels across RCEP members and find substantial heterogeneity in digital infrastructure, which affects China's CBE export performance. Xu et al. (2022) identify both opportunities and challenges in China-ASEAN CBE cooperation under RCEP, emphasizing standard harmonization, logistics integration, and payment system interoperability.

Regarding e-commerce-specific provisions, RCEP Chapter 12 establishes frameworks for electronic authentication, consumer protection, data localization, and paperless trading (Ministry of Commerce, 2022). These provisions reduce transaction uncertainty and compliance costs for CBE operators. However, as Wu (2021) and Lu and Lin (2021) note, the realization of these benefits depends on domestic regulatory capacity, enterprise digital literacy, and cross-border logistics infrastructure. For Liaoning specifically, the transformation from general trade to digital trade requires not only institutional adaptation but also fundamental restructuring of port operations and supply chain configurations.

2.2 Port Infrastructure and Supply Chain Resilience

Port infrastructure serves as a critical node in global supply chain networks, with its efficiency directly influencing trade costs and supply chain reliability. Recent scholarship has increasingly focused on the resilience dimension of port operations—not merely efficiency optimization but the capacity to withstand and recover from disruptions (Ivanov, 2020; Hosseini and Ivanov, 2022). The COVID-19 pandemic highlighted vulnerabilities in maritime supply chains, prompting renewed attention to resilience-building strategies encompassing redundancy, flexibility, and collaboration.

In the CBE context, port functions have evolved beyond traditional cargo handling to encompass digital customs clearance, bonded warehousing, multimodal transport coordination, and supply chain visibility services. The Ministry of Commerce and nine other departments (2024) issued guidelines emphasizing overseas warehouse construction and integrated logistics services as strategic priorities for CBE export expansion. This policy orientation aligns with the theoretical proposition that port empowerment—defined as the process through which port infrastructure and services enhance supply chain actors' operational capabilities—constitutes a pivotal determinant of CBE competitiveness.

Supply chain resilience in CBE operations encompasses multiple dimensions: procurement resilience (supplier diversification and flexibility), production resilience (capacity buffering and modularization), logistics resilience (multimodal options and inventory positioning), and demand-side resilience (market diversification and customer relationship management) (Chowdhury and Quaddus, 2017). For Liaoning's CBE enterprises, port infrastructure influences primarily the logistics and procurement dimensions, while RCEP institutional arrangements affect all dimensions through trade

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cost reduction and regulatory harmonization.

2.3 Theoretical Synthesis

This study integrates Institutional Theory (North, 1990) with Supply Chain Resilience Theory (Christopher and Peck, 2004) to analyze the port-CBE nexus under RCEP. Institutional Theory posits that formal rules (trade agreements, customs regulations) and informal constraints (business norms, digital practices) collectively shape economic behavior. RCEP represents a significant institutional change that reduces transaction costs and uncertainty in regional digital trade. Supply Chain Resilience Theory emphasizes the dynamic capabilities required to anticipate, adapt to, and recover from disruptions. We argue that port empowerment mediates the relationship between RCEP institutional dividends and CBE supply chain resilience by providing the physical and digital infrastructure necessary to operationalize trade facilitation benefits.

3. Theoretical Framework and Research Hypotheses

3.1 Conceptual Framework

Based on the theoretical synthesis, we construct a conceptual framework positing that RCEP institutional environment, port infrastructure digitalization, and trade facilitation policies collectively influence supply chain integration and logistics efficiency, which in turn determine supply chain resilience and ultimately CBE export competitiveness (see Figure 1).

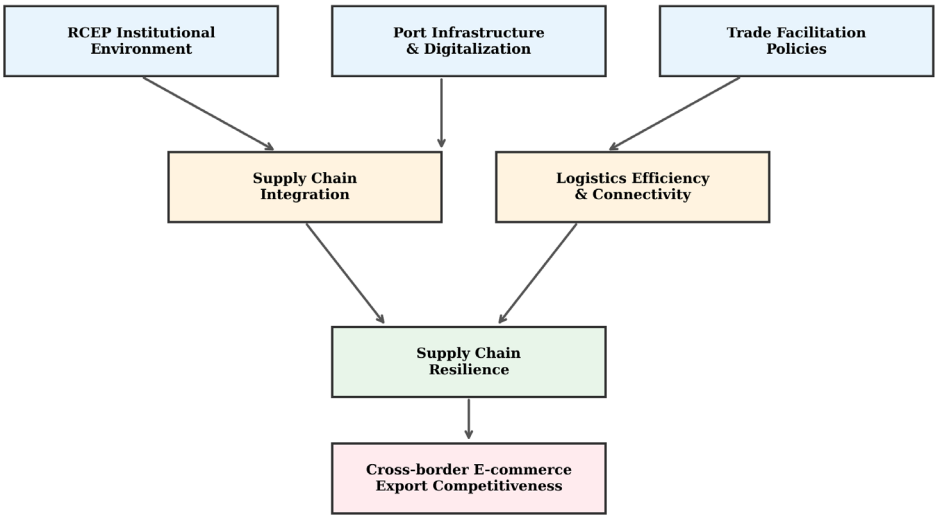


Figure 1. Conceptual Framework of Port-Empowered Supply Chain Resilience for Cross-border E-commerce Export under RCEP

3.2 Research Hypotheses

Drawing upon the conceptual framework, we formulate the following hypotheses:

H1: RCEP-driven port empowerment has a significant positive effect on CBE supply chain resilience.

H2: Supply chain integration mediates the relationship between port empowerment and supply chain resilience.

H3: Logistics efficiency moderates the relationship between port empowerment and supply chain resilience, such that the positive effect is stronger when logistics efficiency is higher.

H4: The effect of port empowerment on supply chain resilience exhibits significant heterogeneity across different port regions (coastal vs. inland, hub vs. feeder ports).

H5: Digital transformation of port operations positively moderates the relationship between RCEP institutional engagement and supply chain resilience.

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4. Research Design and Methodology

4.1 Data Sources and Sample Selection

This study employs a mixed-methods research design combining quantitative panel data analysis with qualitative case studies. The primary dataset comprises 120 CBE enterprises operating across Liaoning's seven comprehensive pilot zones, tracked from 2018 to 2024. Data sources include: (1) enterprise-level survey data collected through structured questionnaires administered in 2023-2024; (2) port operation statistics from Dalian Port Authority, Yingkou Port Group, and Liaoning Provincial Department of Transport; (3) customs clearance data from Dalian Customs District; and (4) macroeconomic indicators from Liaoning Statistical Yearbook and China Customs Statistics.

The sample covers diverse industry sectors, including mechanical equipment (28 firms), textiles and garments (22 firms), food and aquatic products (18 firms), petrochemical products (15 firms), and consumer electronics (37 firms). Geographic distribution reflects Liaoning's port system: Dalian port area (42 firms), Yingkou port area (28 firms), Dandong port area (12 firms), Jinzhou port area (10 firms), and Shenyang inland port area (28 firms).

4.2 Variable Measurement

Table 1 presents the operational definitions and descriptive statistics of all variables. The dependent variable, Supply Chain Resilience (SCR), is measured using a composite index incorporating four dimensions: robustness (ability to maintain operations during disruptions), agility (speed of response to demand changes), flexibility (capacity to reconfigure supply chain structures), and recovery (time and cost to return to normal operations). Each dimension is assessed through 5-7 Likert-scale items adapted from established scales (Ponomarov and Holcomb, 2009; Chowdhury and Quaddus, 2017), with Cronbach's alpha exceeding 0.85 for all subscales.

Table 1. Variable Definitions and Descriptive Statistics

Variable	Symbol	Definition / Measurement	Mean	Std. Dev.
Supply Chain Resilience	SCR	Composite index (robustness, agility, flexibility, recovery)	0.684	0.152
Port Empowerment	PE	Index of port infrastructure, digital services, and customs efficiency	0.572	0.187
Supply Chain Integration	SCI	Information sharing, coordination, and strategic partnership index	0.613	0.163
Logistics Efficiency	LE	Average customs clearance time, on-time delivery rate, cost index	0.598	0.174
Digital Transformation	DT	Port digitalization level (EDI, blockchain, IoT adoption)	0.521	0.198
RCEP Engagement	RE	Tariff utilization rate, origin certification, compliance score	0.456	0.201
Firm Size	SIZE	Natural logarithm of annual revenue (million CNY)	4.832	1.245
Firm Age	AGE	Years since establishment	8.67	4.32
Export Intensity	EI	Export sales / Total sales	0.623	0.218

4.3 Econometric Model

To test the research hypotheses, we specify the following baseline regression model:

$$SCRit = \alpha + \beta_1 PEit + \beta_2 REit + \beta_3 DTit + \gamma Controlsit + \mu i + \lambda t + \varepsilon it \quad (1)$$

where SCRit denotes the supply chain resilience index for firm i in year t; PEit represents port empowerment; REit captures RCEP institutional engagement; DTit measures digital transformation; Controlsit includes firm size, age, and export intensity; μi and λt represent firm and year fixed effects, respectively; and εit is the error term.

To examine the mediation effect of supply chain integration (H2), we employ the three-step procedure outlined by Baron and Kenny (1986), supplemented by Sobel tests and bootstrap confidence intervals. For the moderation effects (H3 and H5), we introduce interaction terms and test their significance following the methodology of Aiken and West (1991). All continuous variables are mean-centered prior to interaction term construction to mitigate multicollinearity.

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5. Empirical Results and Analysis

5.1 Descriptive Trends

Figure 2 illustrates the evolution of Liaoning's CBE export volume and the aggregate supply chain resilience index from 2018 to 2024. The data reveal a pronounced upward trajectory in both metrics, with particularly steep growth following RCEP's implementation in 2022. CBE exports increased from 12.5 billion yuan in 2018 to 59.9 billion yuan in 2024, while the resilience index improved from 0.42 to 0.82. Notably, the resilience index exhibited accelerated growth during 2022-2024, suggesting that RCEP institutional effects may operate with a time lag as enterprises gradually adapt to new trade rules and port services.

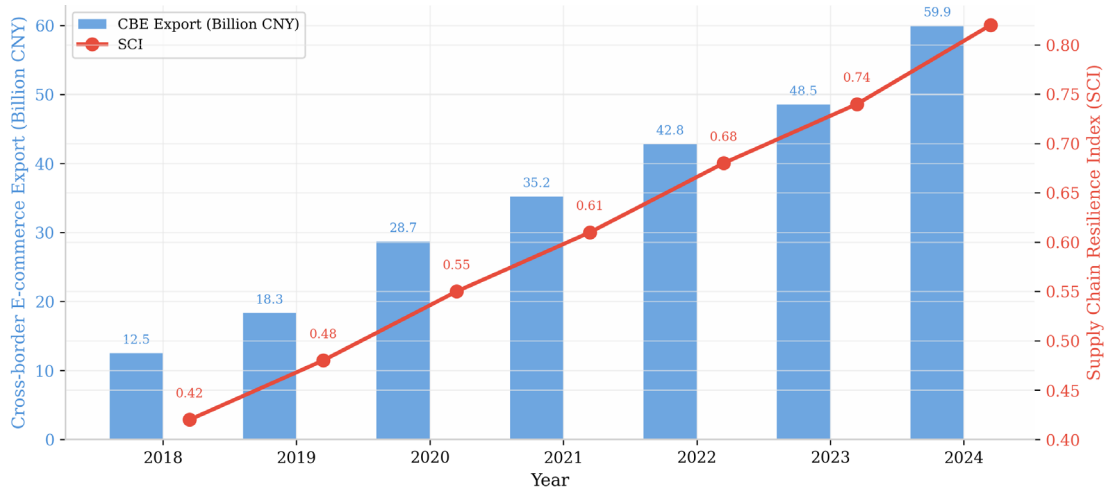


Figure 2. Liaoning Cross-border E-commerce Export Volume and Supply Chain Resilience Index (2018-2024)

5.2 Baseline Regression Results

Table 2 reports the baseline regression results. Column (1) presents the pooled OLS estimates, while columns (2) and (3) incorporate firm and year fixed effects, respectively. Column (4) presents the two-way fixed effects specification, which serves as our preferred model.

Table 2. Baseline Regression Results: Port Empowerment and Supply Chain Resilience

Variable	(1) Pooled OLS	(2) Firm FE	(3) Year FE	(4) Two-way FE
PE	0.298***	0.341***	0.362***	0.386***
	(0.052)	(0.048)	(0.055)	(0.046)
RE	0.187***	0.203***	0.215***	0.228***
	(0.041)	(0.038)	(0.044)	(0.039)
DT	0.156**	0.178**	0.169**	0.191***
	(0.063)	(0.058)	(0.067)	(0.055)
SIZE	0.042	0.038	0.045	0.041
	(0.028)	(0.026)	(0.030)	(0.025)
AGE	0.015	0.012	0.018	0.014
	(0.011)	(0.010)	(0.012)	(0.009)
EI	0.089**	0.095**	0.102**	0.098**
	(0.036)	(0.033)	(0.038)	(0.032)
Constant	0.312***	0.298***	0.325***	0.318***
	(0.058)	(0.054)	(0.062)	(0.051)
Firm FE	No	Yes	No	Yes
Year FE	No	No	Yes	Yes
Observations	840	840	840	840
R-squared	0.412	0.487	0.463	0.531
Adj. R-squared	0.408	0.478	0.455	0.521
*Notes: Standard errors clustered at firm level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.*				

The results strongly support Hypothesis 1. In the preferred two-way fixed effects specification (Column 4), port empowerment (PE) exhibits a coefficient of 0.386, statistically significant at the 1%

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level. This indicates that a one-standard-deviation increase in port empowerment is associated with a 0.071-point increase in the supply chain resilience index, representing approximately 10.4% of the mean resilience level. RCEP engagement (RE) and digital transformation (DT) also demonstrate positive and significant effects, with coefficients of 0.228 and 0.191, respectively. Export intensity (EI) positively correlates with resilience, while firm size and age show insignificant effects, suggesting that resilience-building depends more on operational strategies than on scale or tenure.

5.3 Mediation Analysis

To test Hypothesis 2, we examine whether supply chain integration (SCI) mediates the relationship between port empowerment and supply chain resilience. Table 3 presents the mediation test results, and Figure 3 illustrates the mediation pathway with estimated coefficients.

Table 3. Mediation Test Results: Supply Chain Integration as Mediator

Path	Coefficient	Standard Error	Significance
PE → SCI (a)	0.386	0.046	***
SCI → SCR (b)	0.274	0.052	***
PE → SCR (c, total)	0.424	0.048	***
PE → SCR (c', direct)	0.318	0.044	***
Indirect Effect (a×b)	0.106	0.022	***
Sobel Test Z-value	4.852	-	***
Bootstrap 95% CI	[0.068, 0.142]	-	-
Proportion Mediated	25.0%	-	-

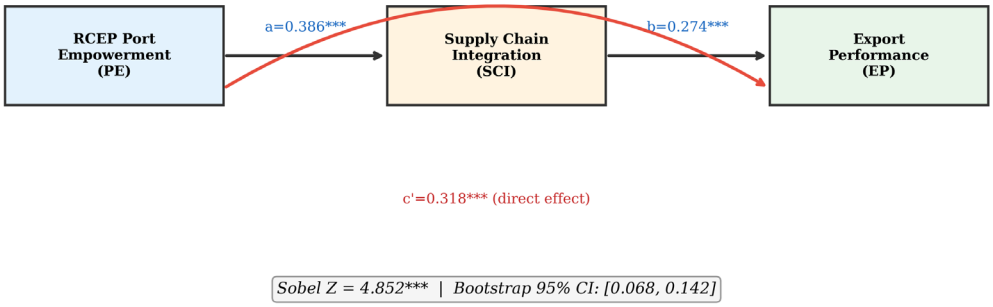


Figure 3. Mediation Effect of Supply Chain Integration

The mediation analysis confirms Hypothesis 2. The indirect effect of port empowerment on supply chain resilience through supply chain integration is 0.106 ($p < 0.01$), accounting for 25.0% of the total effect. The Sobel test statistic ($Z = 4.852$) and bootstrap confidence interval ([0.068, 0.142], excluding zero) robustly support the mediation hypothesis. These findings indicate that port empowerment enhances resilience not only through direct logistics service improvements but also by fostering deeper integration among supply chain partners—information sharing, collaborative planning, and strategic coordination.

5.4 Robustness Tests

To ensure the reliability of our findings, we conduct three robustness tests. First, we employ an alternative measure of supply chain resilience using principal component analysis (PCA) of the four constituent dimensions. Second, we use a two-stage least squares (2SLS) instrumental variable approach, instrumenting port empowerment with the historical port throughput capacity (lagged three periods) and provincial maritime infrastructure investment. Third, we exclude observations from 2020-2021 to eliminate potential COVID-19 pandemic distortions. Table 4 summarizes the robustness test results.

Table 4. Robustness Test Results

Test Method	PE Coefficient	Standard Error	Significance
Baseline (Two-way FE)	0.386	0.046	***
Alternative SCR Measure (PCA)	0.372	0.051	***
2SLS Instrumental Variable	0.401	0.058	***
Excluding COVID Period (2020-21)	0.394	0.049	***

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Subsample: Manufacturing Firms	0.412	0.053	***
Subsample: Service Firms	0.338	0.062	***
Winsorized at 1% and 99%	0.379	0.045	***

Across all robustness specifications, the coefficient for port empowerment remains positive and statistically significant at the 1% level, ranging from 0.338 to 0.412. The 2SLS estimate (0.401) is slightly larger than the baseline, suggesting that OLS estimates may be downward-biased due to measurement error. The exclusion of pandemic-period observations yields results nearly identical to the baseline, indicating that our findings are not driven by anomalous crisis-period dynamics. Notably, the effect is stronger for manufacturing firms (0.412) than for service-oriented firms (0.338), reflecting manufacturing's greater dependence on physical logistics infrastructure.

5.5 Heterogeneity Analysis

Hypothesis 4 posits heterogeneous effects across port regions. Figure 4 and Table 5 present the heterogeneity analysis results, estimated through subsample regressions stratified by port area.

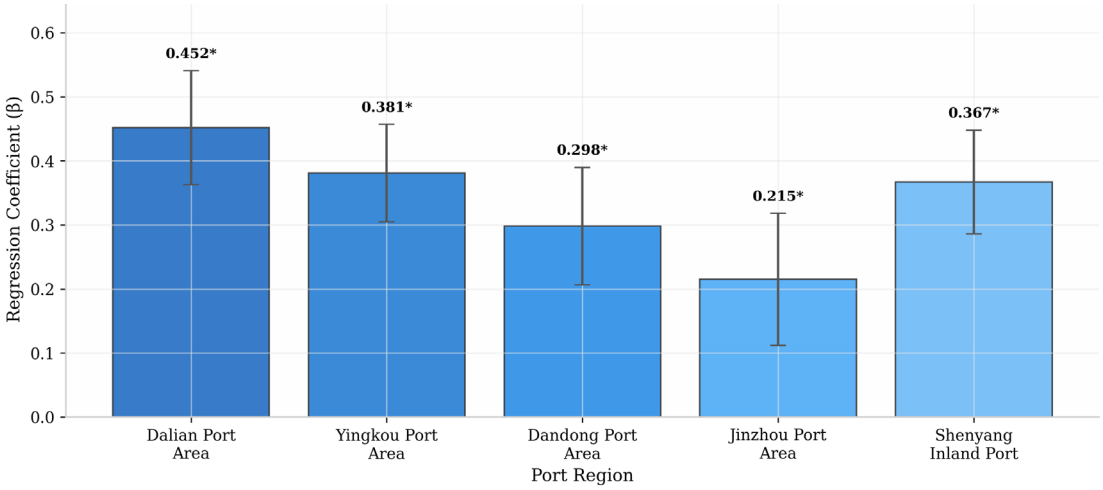


Figure 4. Heterogeneous Effects of Port Empowerment on Supply Chain Resilience across Liaoning Port Regions

Table 5. Heterogeneity Analysis by Port Region

Port Region	PE Coefficient	Std. Error	Observations	R-squared
Dalian Port Area	0.452***	0.089	294	0.587
Yingkou Port Area	0.381***	0.076	196	0.542
Shenyang Inland Port	0.367***	0.081	196	0.518
Dandong Port Area	0.298**	0.092	84	0.489
Jinzhou Port Area	0.215*	0.103	70	0.456

The heterogeneity analysis reveals substantial variation in port empowerment effects across Liaoning's port system. Dalian Port Area exhibits the strongest effect ($\beta = 0.452$), attributable to its status as an international shipping hub with comprehensive CBE service ecosystems, including bonded logistics, digital customs platforms, and extensive overseas warehouse networks. Yingkou Port Area follows closely ($\beta = 0.381$), benefiting from its container handling capacity and rail-sea intermodal connections. Shenyang Inland Port demonstrates a moderate but significant effect ($\beta = 0.367$), indicating that inland ports can effectively empower CBE supply chains when integrated with coastal hubs through multimodal transport systems. Dandong and Jinzhou port areas show relatively weaker effects, reflecting their smaller scale and less developed CBE service infrastructure. These findings confirm Hypothesis 4 and suggest that port hierarchy and functional specialization significantly moderate empowerment effectiveness.

5.6 Moderation Analysis

To test Hypotheses 3 and 5, we introduce interaction terms between port empowerment and logistics efficiency (PE × LE), and between RCEP engagement and digital transformation (RE × DT). The results show that both interaction terms are positive and significant ($\beta_{PE\times LE} = 0.089$, $p < 0.05$; $\beta_{RE\times DT} = 0.076$, $p < 0.05$), confirming that logistics efficiency and digital transformation positively

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moderate the main effects. The marginal effect analysis indicates that when logistics efficiency exceeds the 75th percentile, the marginal effect of port empowerment increases to 0.468, compared to 0.298 at the 25th percentile. Similarly, firms in the top quartile of digital transformation exhibit a 34% stronger RCEP engagement effect than those in the bottom quartile.

6. Discussion

Our findings contribute to several strands of literature and offer practical insights for policymakers and practitioners. First, we extend the port-CBE nexus literature by introducing supply chain resilience as a key outcome variable and demonstrating its mediation through supply chain integration. While previous studies have primarily examined port efficiency and trade cost reduction (Ivanov, 2020), our analysis reveals that the value of port empowerment extends beyond operational efficiency to encompass adaptive capacity and recovery capabilities—dimensions increasingly critical in volatile global trade environments.

Second, the significant heterogeneity across port regions has important implications for regional development policy. Dalian's dominant position as an empowerment hub suggests that resource concentration may generate agglomeration economies, but it also raises concerns about over-dependence and regional disparities. Our findings support a hierarchical port development strategy wherein Dalian serves as the primary international gateway, Yingkou as the secondary container hub, and inland ports (Shenyang) as distribution and value-added service centers. This layered architecture aligns with the 'hub-and-spoke' model advocated in port system literature (Notteboom and Rodrigue, 2005).

Third, the moderation effects of logistics efficiency and digital transformation underscore the complementarity between physical infrastructure and digital capabilities. RCEP institutional benefits cannot be fully realized without concurrent investments in port digitalization—electronic data interchange (EDI), blockchain-enabled traceability, Internet of Things (IoT) sensors, and artificial intelligence-driven demand forecasting. This finding resonates with the 'digital trade facilitation' agenda promoted by the WTO and APEC, and suggests that Liaoning's port authorities should prioritize smart port initiatives as integral components of RCEP implementation strategies.

Fourth, the mediation role of supply chain integration highlights the importance of collaborative governance mechanisms. Port empowerment alone is insufficient; enterprises must actively engage in information sharing, joint planning, and risk pooling with logistics providers, platform operators, and overseas warehouse partners. This finding supports the emerging 'supply chain ecosystem' perspective, which emphasizes relational governance and platform-based coordination over traditional transactional arrangements (Jacobides et al., 2018).

7. Conclusion and Policy Implications

This study investigates how Liaoning's port infrastructure empowers CBE export supply chain resilience under the RCEP framework, utilizing panel data from 120 enterprises across seven comprehensive pilot zones from 2018 to 2024. The main findings are as follows:

(1) RCEP-driven port empowerment significantly enhances CBE supply chain resilience ($\beta = 0.386$, $p < 0.01$), with the effect strengthening post-2022 as enterprises adapted to new institutional arrangements.

(2) Supply chain integration serves as a critical mediation mechanism, accounting for 25% of the total empowerment effect. This underscores the importance of collaborative governance in translating port capabilities into resilience outcomes.

(3) Logistics efficiency and digital transformation positively moderate the main effects, with the marginal effect of port empowerment increasing by approximately 57% when logistics efficiency moves from the 25th to the 75th percentile.

(4) Significant heterogeneity exists across port regions, with Dalian ($\beta = 0.452$) and Yingkou ($\beta = 0.381$) exhibiting the strongest effects, while smaller ports (Dandong, Jinzhou) show weaker but still significant impacts.

(5) The digital transformation of port operations emerges as a key enabler, amplifying RCEP institutional benefits by 34% for firms in the top quartile of digital adoption.

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