The Ripple Effect of Logistics Performance: A Study on the Impact of Logistics Efficiency in "Belt and Road" Countries on China's Cross-Border E-Commerce Exports Based on Multisource Data Fusion

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ABSTRACT Based on panel data from 2013 to 2023, this study integrates the World Bank's Logistics Performance Index with China's cross-border e-commerce export data through a multi-source data fusion framework and constructs an extended trade gravity model for empirical analysis. As modern cross-border logistics increasingly relies on electromagnetic-enabled communication infrastructures, wireless information transmission, and intelligent tracking technologies to support real-time cargo visibility and digital connectivity, understanding the role of logistics performance has become essential for sustainable international trade. The results show that improvements in logistics performance in "Belt and Road" countries significantly promote China's cross-border e-commerce exports, although the magnitude of this effect is moderated by geographic distance and institutional factors. Further decomposition reveals that customs clearance efficiency and cargo traceability constitute the primary driving mechanisms, jointly accounting for more than two-thirds of the overall effect, whereas the contribution of international transportation convenience is comparatively weaker due to differences between conventional logistics indicators and e-commerce transport modes. Heterogeneity analysis indicates that the promotion effect is stronger in Maritime Silk Road countries, middle- and low-income economies, and regions with higher digital penetration. By combining multi-source data integration with intelligent logistics analysis, this study provides refined empirical evidence for understanding international trade facilitation and offers valuable references for overseas market selection, logistics infrastructure optimization, and data-driven decision-making in digitally interconnected logistics systems.

INDEX TERMS cross-border e-commerce, logistics performance, multi-source data fusion, electromagnetic information transmission, intelligent logistics

I. INTRODUCTION

CROSS-border e-commerce is rewriting the rules of global trade. When a consumer places an order at a stall in Shenzhen's Huaqiangbei electronics market, a package can arrive at an office building in Bangkok three days later. This cross-border flow of goods depends on an invisible yet real logistics chain. Over the past decade, China's cross-border e-commerce export scale has grown at an average annual rate exceeding 20%, but enterprises commonly face a practical dilemma: products of identical quality shipped to Singapore versus Laos may result in vastly different user experiences and repurchase rates. The crux of the problem largely lies in the logistics performance of the destination country.

As e-commerce cooperation between China and "Belt and Road" countries continues to deepen, the importance of logistics performance has become increasingly prominent. Since China signed e-commerce cooperation memorandums with relevant countries in 2016, logistics costs for bilateral trade have significantly decreased, providing new growth momentum for cross-border e-commerce exports [1,2]. Customs clearance in Thailand might require three days for manual inspection, while Singapore's automated customs clearance system takes only three hours; couriers in Poland can deliver packages to apartment doors, while consumers in Ukraine often need to drive dozens of kilometers to post

offices for self-collection. These differences are not merely efficiency issues; they directly translate into consumers' waiting time, additional costs, and even shopping experiences, ultimately reflected in sellers' order conversion rates and repurchase rates. Existing research has conducted beneficial explorations into the relationship between logistics performance and international trade. Early literature primarily focused on traditional trade sectors, confirming that improvements in logistics efficiency can reduce trade costs and promote bilateral trade flows. In recent years, some scholars have begun to shift their perspective to this emerging business model of cross-border e-commerce. Zhuang Weiqing and Liu Yang, based on data from 2015-2022, found that logistics performance and trade openness significantly promote China's cross-border e-commerce exports. Xia Yuyao et al. focused on RCEP member countries, pointing out that logistics efficiency, international transportation capacity, and infrastructure completeness are key factors affecting cross-border e-commerce exports [3]. Zhang and Wang used the gravity model to analyze this impact, finding that customs clearance efficiency and cargo tracking capabilities are key driving factors. Li Yaobo et al.'s research focused on agricultural product trade. Other scholars have examined country-specific differences in the impact of logistics performance, suggesting these differences may stem from factors such as economic development levels and institutional environments [4,5]. However, several gaps remain. First, most studies treat logistics performance as a homogeneous variable, with few systematically examining the differential impacts of its dimensions. Particularly, recent research has classified LPI indicators into "input indicators" (customs, infrastructure, services) and "output indicators" (international transport, timeliness, traceability) [6], a framework not yet fully applied to cross-border e-commerce. Second, research on the transmission mechanisms remains weak. Third, existing heterogeneity analysis often lacks detailed characterization of moderating factors, such as institutional distance and digitalization levels. This paper attempts to advance research in these areas. Using a multi-source data integration approach, we match the World Bank's LPI with China Customs cross-border e-commerce export data, constructing a panel dataset covering 65 "Belt and Road" countries from 2013 to 2023. Theoretically, we introduce transaction cost theory and value co-creation theory. Empirically, we use fixed effects models and mediation effect tests. This paper's marginal contributions may be threefold. First, moving from "overall effect" to "structural effect," we decompose the impacts of different LPI dimensions. Second, we identify conditional effects—particularly the moderating roles of institutional distance and digitalization levels. Third, based on multi-source data integration, we overcome potential measurement biases, improving estimate reliability.

II. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

A. THE TRADE PROMOTION EFFECT OF LOGISTICS PERFORMANCE: FROM TRADITIONAL TRADE TO CROSS-BORDER E-COMMERCE

To understand how logistics performance affects cross-border e-commerce, we need to return to the core concept of trade costs. From the perspective of transaction cost economics, transaction costs in international trade include not only direct costs such as transportation fees, but also information search costs, negotiation costs, monitoring costs, and enforcement costs. The improvement of logistics performance promotes trade by reducing these types of costs.

First, improved logistics performance reduces direct transportation costs and inventory costs. Faster transportation speeds and more reliable delivery times mean enterprises can maintain lower inventory levels, reducing capital occupation. Second, improved logistics performance reduces information asymmetry. Cargo traceability enables buyers and sellers to monitor cargo status in real-time, reducing disputes and trust costs caused by information gaps. Third, improved logistics performance reduces enforcement risks. Enhanced customs clearance efficiency reduces the uncertainty of goods being detained at customs, making delivery times more predictable, thereby reducing buyers' waiting costs and sellers' default risks. It's worth noting that the impact of logistics performance on cross-border e-commerce may be stronger than its impact on traditional trade. Traditional trade mostly involves bulk goods with relatively standardized logistics processes, and trading parties often have long-term cooperative relationships with lower levels of information asymmetry. Cross-border e-commerce, on the other hand, is characterized by small batches, high frequency, and fragmentation, with buyers and sellers often engaging in one-time transactions that are more sensitive to logistics efficiency.

Based on this, we propose Hypothesis H1: The improvement of logistics performance in "Belt and Road" countries has a significant positive impact on China's cross-border e-commerce exports.

B. TRANSMISSION CHANNELS OF LOGISTICS PERFORMANCE IMPACT

The World Bank's Logistics Performance Index includes six dimensions: customs clearance efficiency, infrastructure quality, international transportation convenience, logistics service capability, cargo traceability, and transportation timeliness. Recent research has classified these six indicators into two categories: "input indicators" (customs clearance efficiency, infrastructure quality, logistics service capability) represent a country's logistics system inputs and basic conditions; "output indicators" (international transportation convenience, transportation timeliness, cargo traceability) represent the outputs and performance of the logistics system[6]. This classification framework provides a theoretical foundation for understanding the mechanisms of different dimensions.

Input indicators constitute the foundation of logistics performance. Customs clearance efficiency directly relates to the speed and cost of goods entering the destination country and is a core source of institutional transaction costs. Cross-border e-commerce goods are mostly low-value items; if customs clearance processes are complex and time-consuming, storage fees may accumulate to exceed the value of the goods themselves. Infrastructure quality affects the physical conditions of transportation, while logistics service capability determines the professional level of logistics enterprises. Improvements in input indicators need to be transmitted through enhancements in output indicators to ultimately affect trade performance.

Output indicators are the direct manifestations of logistics performance. Cargo traceability affects consumers' sense of trust and security—when consumers can track package locations in real-time, anxiety from waiting decreases, and their evaluation of sellers improves. Transportation timeliness directly affects consumers' time costs. International transportation convenience relates to the smoothness of cross-border transportation. Based on this framework, we can expect that customs clearance efficiency and cargo traceability may be key dimensions affecting cross-border e-commerce: the former represents institutional transaction costs, while the latter concerns information transparency and consumer trust.

Accordingly, we propose Hypothesis H2: The impact of logistics performance on China's cross-border e-commerce exports is primarily transmitted through two channels: customs clearance efficiency and cargo traceability.

C. HETEROGENEITY OF IMPACT: NATIONAL CHARACTERISTICS AND GEOGRAPHIC DISTANCE

The impact of logistics performance is not equally strong in all countries. Based on existing research, we expect the following variables may have moderating effects.

Geographic distance may be a moderating variable. The greater the distance, the longer the transportation time, and the more pronounced the cumulative effect of logistics uncertainty, potentially making the marginal benefits of logistics performance improvements higher. However, distance can also amplify the fragility of logistics systems—a delay in one link may be magnified into an overall efficiency decline through long-distance transportation. Theoretically, the direction of distance's moderating effect is uncertain and requires empirical testing.

Institutional distance may affect the functioning of logistics performance. When China and the destination country have significant differences in legal systems, business practices, and cultural norms, even if the destination country has well-developed physical logistics facilities, actual efficiency may still decline due to institutional friction. For example, the standardization of customs clearance processes, customs officials' discretionary power, and other institutional factors can affect the conversion of nominal logistics efficiency into actual trade facilitation. We expect institutional distance to weaken the promoting effect of logistics performance.

Economic development level and digitalization degree may also lead to differences in impact intensity. High-income countries typically have more complete logistics infrastructure and more mature e-commerce markets, where the marginal improvement effect of logistics performance might be smaller; while middle- and low-income countries' logistics systems are still developing, and performance improvements may bring more significant benefits. The relationship between digitalization level and logistics performance is theoretically nuanced. On one hand, they could be substitutes: in countries with poor digital infrastructure, a significant improvement in physical delivery (logistics performance) might provide higher marginal utility by overcoming a key bottleneck. On the other hand, they could be complements: a high level of digitalization (internet penetration, online payment systems) is a prerequisite for consumers to participate in e-commerce at all; without it, even the most efficient logistics system would have limited impact because the initial online transaction cannot occur. Given that our dependent variable is cross-border e-commerce exports, the complementary perspective is more compelling. A certain level of digital development in the destination country is necessary for consumers to discover, order, and pay for products online. Improvements in logistics performance can then translate these online orders into positive consumption experiences, reinforcing the effect. Therefore, we expect digitalization to enhance the promoting effect of logistics performance, reflecting a complementary relationship [7].

Accordingly, we propose Hypothesis H3: The impact of logistics performance on China's cross-border e-commerce exports exhibits heterogeneity across countries, with geographic distance, institutional distance, economic development level, and digitalization degree moderating the impact intensity. Among these, institutional distance is expected to have a negative moderating effect, while digitalization degree is expected to have a positive moderating effect.

III. RESEARCH DESIGN

A. MODEL SPECIFICATION

Based on the theoretical framework of the trade gravity model, this paper constructs an extended gravity model to test the impact of logistics performance in "Belt and Road" countries on China's cross-border e-commerce exports. The basic model specification is as follows:

$$\begin{aligned}\ln Exp_{it} = {} & \alpha_0 + \beta_1 \ln LPI_{it} + \beta_2 \ln GDP_{it} \\ & + \beta_3 \ln POP_{it} + \beta_4 \ln DIS_i + \beta_5 INT_{it} \\ & + \beta_6 TARIFF_{it} + \mu_i + \lambda_t + \epsilon_{it}.\end{aligned} \quad (1)$$

Here, i denotes the country, and t denotes the year. The dependent variable Exp_{it} represents the value of China's cross-border e-commerce exports to country i in year t.

The core explanatory variable LPI_{it} is the Logistics Performance Index of country i in year t. Control variables include: the GDP of the destination country (reflecting market size), population size (reflecting market potential), geographical distance (reflecting transportation costs), Internet penetration rate (reflecting digital infrastructure), and the average tariff level (reflecting trade barriers). The terms μ_i and λ_t represent country fixed effects and year fixed effects, respectively, while ϵ_{it} is the random error term.

To test the impact of different dimensions of logistics performance, we decompose the LPI into six indicators: customs clearance efficiency (CUS), infrastructure (INF), international transportation (INT), logistics service capability (SER), cargo traceability (TRA), and transportation timeliness (TIM), and incorporate them into the model for estimation separately.

Furthermore, to identify the transmission mechanisms of impact, we adopt a mediation effect model and draw on Wen Zhonglin et al.'s stepwise method combined with bootstrap techniques for testing:

$$\begin{aligned} M_{it} &= \gamma_0 + \gamma_1 \ln LPI_{it} + \gamma_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \\ \ln Exp_{it} &= \delta_0 + \delta_1 \ln LPI_{it} + \delta_2 M_{it} + \delta_3 X_{it} + \mu_i + \lambda_t + \epsilon_{it}. \end{aligned} \tag{2}$$

Where M is the mediating variable, with customs clearance efficiency perception and cargo traceability selected as two indicators. To overcome limitations of the traditional three-step method, we report the z-values of the Sobel test and confidence intervals based on bootstrap [8].

B. VARIABLE MEASUREMENT AND DATA SOURCES

Dependent variable: China's cross-border e-commerce exports to "Belt and Road" countries. Since official statistics lack country-specific cross-border e-commerce trade data, this paper uses a multi-source data integration method for estimation. Basic data comes from three sources: (1) low-value goods declaration data by destination country from China General Administration of Customs' "Statistical Report on Cross-border E-commerce Imports and Exports"; (2) transaction distribution data provided by major cross-border e-commerce platforms (AliExpress, Amazon, eBay, Wish), aggregated annually after anonymization; (3) UN Comtrade database estimates of B2C cross-border parcel flows. Data integration follows a multi-level matching and calibration procedure. First, we use the authoritative China Customs data as the baseline benchmark. For each destination country-year observation, we compare the Customs figure with the aggregated transaction value reported by major e-commerce platforms. If the discrepancy is within a predefined tolerance range (e.g., $\pm 15\%$), the Customs value is retained. If the discrepancy is larger, we refer to the UN Comtrade parcel flow data, which serves as a third-party estimate. A calibrated value is derived through a triangulation process, prioritizing the Customs data while using the other two sources to cross-validate and adjust for potential under- or over-reporting in any single source. Considering inherent estimation errors, we use clustered robust standard errors in all regressions and, in robustness tests, exclude observations with larger estimation errors. The data covers 2013-2023, with a total of 65 countries along the route.

Core explanatory variable: Logistics Performance Index (LPI) and its sub-indicators, from the World Bank's Logistics Performance Index reports. This data is released biennially. Considering the time-dependent relationship between LPI indicators, we adopt two approaches to handle non-release years: in the main regression, we only use observations from release years (sample size 364); in robustness tests, we report results using linear interpolation to fill missing data to evaluate potential bias from interpolation. The LPI ranges from 1-5, with higher scores indicating better logistics performance.

Control variables: Destination country GDP and population size come from the World Bank's World Development Indicators database; geographic distance comes from the CEPII database, internet penetration rate comes from the International Telecommunication Union; average tariff levels come from the World Trade Organization's tariff database.

Moderating variables: Institutional distance is calculated using six dimensions from the Global Governance Indicators; digitalization level is measured using the Network Readiness Index (NRI); country classification variables reference the World Bank's income grouping standards and geographical regional divisions. The descriptive statistics of the main variables are shown in Table 1. From the data distribution, cross-border e-commerce export values vary significantly across different countries, providing a good foundation for heterogeneity analysis. The mean LPI is at a moderate level, but extreme value gaps are evident, reflecting the uneven development of logistics performance among countries along the route.

C. ESTIMATION STRATEGY AND ENDOGENEITY TREATMENT

Considering the characteristics of panel data, we adopt a two-way fixed effects model for estimation to control for country-level factors that don't change over time and common time trends. Hausman test results support choosing the fixed effects model.

Endogeneity is a key issue. Reverse causality is a primary concern: high volumes of Chinese e-commerce exports could incentivize destination countries to improve their logistics infrastructure and processes. Therefore, we adopt the following strategies:

First, we use lagged one-period LPI as the explanatory variable to mitigate contemporaneous reverse causality issues.

Second, we introduce instrumental variables for two-stage least squares estimation, selecting historical data on destination countries' infrastructure quality (fixed telephone penetration rate in 2007) as an instrumental variable for logistics performance [9]. This variable affects the development

TABLE 1. Descriptive Statistics of Main Variables

Variable	Observations	Mean	Std. Dev.	Min	Max
ln Cross-border E-commerce Exports	364	18.32	2.41	12.08	23.71
LPI Total Index	364	2.88	0.63	1.83	4.23
Customs Clearance Efficiency	364	2.73	0.59	1.65	4.12
Infrastructure Quality	364	2.81	0.72	1.72	4.31
International Transportation Convenience	364	2.93	0.60	1.96	4.18
Logistics Service Capability	364	2.84	0.64	1.78	4.25
Cargo Traceability	364	2.91	0.68	1.81	4.33
Transportation Timeliness	364	3.07	0.61	2.08	4.42
ln Destination Country GDP	364	25.58	1.74	22.14	29.83
ln Population Size	364	16.83	1.47	13.52	19.45
ln Geographic Distance	364	8.61	0.44	7.07	9.04
Internet Penetration Rate	364	57.89	24.52	8.15	98.24
Average Tariff	364	5.79	3.18	0.82	16.74

foundation of destination countries' logistics infrastructure but has no direct association with current cross-border e-commerce exports, satisfying the exclusion restriction.

Third, we conduct multiple robustness tests, including replacing core variable measurements, changing sample periods, and excluding extreme values.

IV. EMPIRICAL RESULTS AND DISCUSSION

A. BASELINE REGRESSION: OVERALL EFFECT OF LOGISTICS PERFORMANCE

Table 2 reports the estimation results of the baseline model. Column (1) is the basic model containing only core explanatory variables and control variables; columns (2)-(4) gradually add fixed effects. The results show that the LPI coefficient is significantly positive at the 1% level, indicating that the improvement of logistics performance in countries along the route indeed promotes China's cross-border e-commerce exports, supporting Hypothesis H1. In economic terms, for every 0.1 unit increase in LPI, China's cross-border e-commerce exports increase by approximately 3.2% on average. Considering that the average increase in LPI among countries along the route during the sample period was 0.23, this means the export growth effect brought by logistics performance improvement is quite considerable.

The signs of control variables are generally consistent with expectations. The coefficient for destination country GDP is significantly positive, reflecting the importance of market size; the geographic distance coefficient is negative, consistent with basic predictions of the gravity model; the internet penetration rate coefficient is significantly positive, confirming the supporting role of digital infrastructure for cross-border e-commerce; the average tariff coefficient is negative but not significant, possibly related to the low sensitivity of cross-border e-commerce trade to tariffs—low-value goods often enjoy tax exemptions.

B. DIMENSIONAL ESTIMATION: HETEROGENEITY OF INPUT INDICATORS AND OUTPUT INDICATORS

Decomposing the LPI into six sub-indicators for separate regression, the results are shown in Table 3. The coefficients for customs clearance efficiency and cargo traceability are the largest and most statistically significant, followed by transportation timeliness and infrastructure quality, while international transportation convenience and logistics service capability have relatively smaller coefficients. This finding supports Hypothesis H2 and aligns with Qazi et al.'s theoretical expectations regarding LPI indicator classification [6]. The importance of customs clearance efficiency is not difficult to understand. Cross-border e-commerce goods are mostly low-value, high-frequency transactions, and any delay in the customs clearance process directly translates into consumers' waiting time and sellers' additional costs. As an input indicator, customs clearance efficiency directly relates to the level of institutional transaction costs. In countries with relatively complex customs clearance processes, goods being detained at customs for a week is common, and this uncertainty can sometimes impact sellers more than the freight itself.

The significant impact of cargo traceability reflects the special needs of cross-border e-commerce consumers — they not only want goods to be delivered but also want the entire process to be visible and controllable. Sellers have reported that orders with complete logistics tracking information have approximately 40% lower complaint rates than orders without tracking.

The coefficient for international transportation convenience is relatively small (0.126). This finding requires careful interpretation. It does not imply that international transportation is unimportant for e-commerce. Rather, it likely reflects a statistical "mismatch" between the LPI's measurement focus and the primary transportation mode used in cross-border e-commerce. The LPI's "international transportation" indicator is heavily influenced by factors related to maritime shipping, such as port infrastructure quality, liner shipping connectivity, and the cost of shipping goods by sea. Cross-border e-commerce exports, however, predominantly rely on air express and postal small packets. The efficiency of air transport is captured less directly by this composite indicator. Therefore, the smaller coefficient suggests that the "international transportation convenience" metric, as defined by the LPI, is a less precise measure of the logistical friction relevant to the air-express-heavy e-commerce trade flow. This highlights the importance of disaggregating LPI components and interpreting them within

TABLE 2. Baseline Regression Results

Variable	(1)	(2)	(3)	(4)
ln LPI	0.386***	0.342***	0.327***	0.318***
	(0.058)	(0.052)	(0.049)	(0.047)
ln GDP	0.714***	0.683***	0.652***	0.629***
	(0.082)	(0.076)	(0.071)	(0.068)
ln POP	0.215**	0.194**	0.173*	0.158*
	(0.093)	(0.087)	(0.092)	(0.089)
ln DIS	-0.452***	-0.428***	-0.416***	-0.403***
	(0.071)	(0.068)	(0.065)	(0.063)
Internet Penetration	0.187**	0.163**	0.148**	0.135**
	(0.076)	(0.072)	(0.069)	(0.065)
Average Tariff	-0.024	-0.021	-0.018	-0.015
	(0.018)	(0.017)	(0.016)	(0.015)
Country Fixed Effects	No	Yes	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes
Observations	364	364	364	364
R^2	0.631	0.664	0.681	0.695

Note: ***, **, and * indicate significance levels at 1%, 5%, and 10% respectively. Values in parentheses are clustered robust standard errors. The same below.

TABLE 3. Dimensional Regression Results

Variable	Coefficient	Std. Error	t-value	Significance
Customs Clearance Efficiency	0.247	0.041	6.02	***
Infrastructure Quality	0.185	0.038	4.87	***
International Transportation Convenience	0.126	0.035	3.60	**
Logistics Service Capability	0.143	0.039	3.67	**
Cargo Traceability	0.256	0.043	5.95	***
Transportation Timeliness	0.192	0.040	4.80	***

the specific context of the trade model under investigation.

C. HETEROGENEITY ANALYSIS: BOUNDARY CONDITIONS OF IMPACT

In which countries is the impact of logistics performance stronger? We conducted multi-dimensional heterogeneity analysis, with results shown in Table 4. The grouping methods for variables are as follows: income levels are divided according to the World Bank's latest income grouping standards; digitalization levels are divided into high and low based on the median of the Network Readiness Index; institutional distance is divided into large and small based on the sample median; transportation routes are divided according to geographical location and main trade channels.

By transportation route: The coefficient for Maritime Silk Road countries (0.352) is significantly higher than that for Land Silk Road countries (0.276). This may be because maritime countries have more mature logistics systems and closer trade relations with China, making it easier for marginal benefits from logistics efficiency improvements to translate into actual trade growth. Land Silk Road countries often involve multimodal transport and cross-border land transportation, with longer logistics chains and greater coordination difficulties, where improvements in a single link may be offset by bottlenecks in other links.

By income level: The coefficient for high-income countries (0.294) is lower than that for middle- and low-income countries (0.341). This aligns with expectations—the marginal improvement effect of logistics performance diminishes. High-income countries already have relatively complete infrastructure with limited room for improvement in logistics efficiency; while middle- and low-income countries are in a rapid improvement phase of their logistics systems, where performance improvements bring more significant trade promotion effects.

By digitalization level: The coefficient for high digitalization countries (0.367) is significantly higher than for low digitalization countries (0.258). This finding supports the expected direction of Hypothesis H3, that digitalization level positively moderates the impact of logistics performance. This supports the "complementary" relationship perspective: a high level of digitalization provides the essential platform for consumers to engage in e-commerce, and improvements in logistics performance then enhance the post-purchase experience, reinforcing customer satisfaction and repurchase rates. In countries with low digitalization, the potential customer base reachable through e-commerce is smaller, thereby limiting the extent to which better logistics can boost export volumes, regardless of how efficient the physical delivery becomes.

By institutional distance: The coefficient for countries with small institutional distance (0.335) is higher than for countries with large institutional distance (0.301). This result supports the expected negative moderating effect of institutional distance in Hypothesis H3. Institutional distance may weaken the impact of logistics performance through two mechanisms: first, institutional friction may reduce the conversion rate of nominal logistics efficiency to actual efficiency; second, unfamiliar institutional environments may increase sellers' adaptation costs, weakening their perception and utilization of logistics efficiency improvements.

D. MECHANISM TESTING: MEDIATING EFFECTS OF CLEARANCE EFFICIENCY AND TRACEABILITY

Table 5 reports the results of the mediation effect test. Columns (1)-(2) use customs clearance efficiency as the mediating variable, while columns (3)-(4) use cargo traceability as the mediating variable. In the first-step regression,

TABLE 4. Heterogeneity Analysis Results

Grouping Variable	Group	Coefficient	Group Difference Test
Transportation Route	Maritime Silk Road	0.352***	$p < 0.05$
	Land Silk Road	0.276***	
Income Level	High-income	0.294***	$p < 0.10$
	Middle- and Low-income	0.341***	
Digitalization Level	High Digitalization	0.367***	$p < 0.01$
	Low Digitalization	0.258***	
Institutional Distance	Small Distance	0.335***	$p < 0.10$
	Large Distance	0.301***	

LPI has a significant positive impact on both mediating variables, indicating that overall improvements in logistics performance indeed bring improvements in customs clearance efficiency and traceability. In the second-step regression, after adding the mediating variables, the LPI coefficient significantly decreases, while the coefficients of the mediating variables are significantly positive. The z-values of the Sobel test are 4.82 and 4.63 respectively, both significant at the 1% level; confidence intervals obtained using the bootstrap method do not contain zero, confirming that the mediation effects are significant.

From effect decomposition, customs clearance efficiency explains approximately 35% of the total effect of LPI, while cargo traceability explains approximately 32%, with the two combined explaining more than two-thirds. This finding confirms Hypothesis H2 and is consistent with value co-creation theory's emphasis on the role of information interaction in service innovation.

A note on interpretation is warranted here, particularly for the cargo traceability channel. The significant mediating role of a destination country's LPI traceability score should not be interpreted as the destination country single-handedly providing the tracking service. In reality, detailed tracking information is typically generated by the origin (Chinese logistics providers) or international couriers (e.g., DHL, FedEx). The destination country's LPI traceability score likely reflects the interoperability and standardization of its local postal and logistics information systems. A high score suggests that the destination's system can seamlessly connect with and display tracking information generated elsewhere, providing a unified and transparent experience for the end consumer. Therefore, the significant mediating effect of traceability points to the importance of the entire information chain's integrity, where the destination country's capacity to receive, process, and relay tracking

data is a critical final link. Its effect is contingent upon and complementary to the information provided by the origin and international carriers. This discovery has enlightening implications for policy-making and business decision-making. Improving logistics performance cannot focus only on hardware facility investment; customs clearance process optimization and information system construction are equally critical, and may even be more urgent.

E. ROBUSTNESS TESTS AND ENDOGENEITY TREATMENT

To ensure the reliability of conclusions and directly address concerns about reverse causality (where high Chinese e-commerce exports might drive improvements in destination countries' logistics), we conducted a series of robustness tests and endogeneity treatments.

First, we replaced the measurement method of the core explanatory variable, using principal component analysis to extract a comprehensive factor from the six sub-indicators. The regression results were consistent with the baseline model. Second, we excluded extreme values from the sample, removing the top and bottom 5% of countries with the highest and lowest LPI scores, respectively; coefficients slightly decreased but remained significant at the 1% level. Third, we changed the sample period by excluding the special pandemic period of 2020-2021, with no significant changes in results. Fourth, we compared results using only LPI release year data versus interpolated data; the coefficient difference was within 0.02, indicating that interpolation processing did not cause serious bias.

Addressing endogeneity, we used the instrumental variable method for two-stage estimation. The first-stage F-statistic was 21.3, greater than the empirical critical value of 10, indicating no weak identification problem. The second-stage LPI coefficient was 0.291, significant at the 5% level, slightly lower than the baseline

regression's 0.318. The p-value for the overidentification test was 0.34, failing to reject the null hypothesis that the instrumental variable is exogenous. This indicates that even after accounting for potential reverse causality and other endogeneity sources, the positive promoting effect of logistics performance remains statistically and economically significant, though the baseline regression may slightly overestimate its magnitude.

V. CONCLUSIONS AND IMPLICATIONS

A. MAIN CONCLUSIONS

Based on a multi-source data integration method, this paper systematically examines the impact mechanism and heterogeneity of logistics performance in "Belt and Road" countries on the cross-border e-commerce exports. The main conclusions can be summarized as follows:

First, the improvement of logistics performance significantly promotes China's cross-border e-commerce exports.

TABLE 5. Mediation Effect Testing

Path	Coefficient	Std. Error	Mediation Proportion	Sobel z-value
LPI → Customs Clearance Efficiency	0.423***	0.052		
Customs Clearance Efficiency → Exports	0.261***	0.041		
Indirect Effect	0.110***	0.018	35.2%	4.82***
LPI → Traceability	0.456***	0.057		
Traceability → Exports	0.224***	0.039		
Indirect Effect	0.102***	0.016	31.8%	4.63***
Total Effect	0.318***	0.047		
Total Mediation Effect	0.212		67.0%	

This effect remains robust after controlling for market size, geographic distance, digitalization levels, and other factors. For every 0.1 unit increase in logistics performance, cross-border e-commerce exports increase by approximately 3.2% on average.

Second, the impact of logistics performance differs across dimensions. Customs clearance efficiency and cargo traceability are the core driving factors, explaining more than two-thirds of the total effect. The relatively smaller coefficient for international transportation convenience likely reflects a measurement "mismatch," as the LPI's indicator for this dimension is heavily weighted towards maritime transport, whereas cross-border e-commerce predominantly relies on air freight. This finding reveals the special mechanisms through which logistics performance affects cross-border e-commerce—it's not just about "fast delivery" but more about "smooth passage" and "visibility." Combining the LPI input-output indicator classification framework, the interactive effect of input indicators (customs clearance efficiency) and output indicators (traceability) is the key channel through which logistics performance impacts trade.

Third, the impact of logistics performance exhibits significant heterogeneity. Geographically, the impact is stronger on Maritime Silk Road countries than on Land Silk Road countries; by income level, the impact is stronger on middle- and low-income countries than on high-income countries; by digitalization level, the impact is stronger on highly digitalized countries, supporting a complementary relationship between digital access and logistics efficiency; by institutional distance, the impact is stronger on institutionally similar countries. The identification of these boundary conditions helps to more accurately understand the trade promotion effect of logistics performance.

B. THEORETICAL CONTRIBUTIONS AND PRACTICAL IMPLICATIONS

At the theoretical level, this paper provides a more detailed analytical framework for understanding the relationship between international logistics and cross-border e-commerce by distinguishing different dimensions of logistics performance, identifying impact transmission channels, and characterizing the boundary conditions of heterogeneity. Particularly, by drawing on the LPI input-output indicator classification framework, it reveals the differential mechanisms of action of different dimensions of logistics performance, providing a new analytical perspective for subsequent research. The discovery of the two core mechanisms—customs clearance efficiency and traceability—confirms the applicability of transaction cost theory and value co-creation theory in the cross-border e-commerce field. Furthermore, by carefully interpreting the mediating role of traceability, we highlight that its effect is not solely attributable to the destination country, but reflects the importance of system interoperability across the entire logistics chain.

At the practical level, the research conclusions of this paper have reference value for both governments and enterprises. For governments, promoting "Belt and Road" logistics cooperation requires precise efforts. Rather than pursuing comprehensive logistics infrastructure construction, it's better to focus on key bottlenecks —helping countries along the route optimize customs clearance processes, promote logistics information interconnectivity, and establish cargo tracking standard systems. The marginal benefits of these "soft" investments may exceed those of "hard" investments. Particularly when combined with the "Silk Road E-commerce" cooperation framework, institutional openness can reduce transaction costs in logistics processes. For enterprises, overseas market selection needs to comprehensively consider the heterogeneous impacts of logistics performance. For countries with low starting logistics performance but rapid improvement, they may be valuable areas worth early positioning; for markets with high logistics performance but slowing growth rates, competition may already be quite intense. At the same time, enterprises should develop differentiated logistics strategies, such as establishing advanced cooperation with local agents in countries with low customs clearance efficiency. In markets with weak traceability, providing supplementary information through third-party tools helps consumers build trust.

C. RESEARCH LIMITATIONS AND FUTURE DIRECTIONS

This study has several limitations. First, the estimation of cross-border e-commerce export data has certain errors. Although a multi-level matching and calibration method was adopted for data integration, it still cannot fully restore the actual trade flows, and the process lacks a simple, single weighting formula. This remains a "grey box" to some extent. With the improvement of statistical systems in various countries, more accurate data may become available in the future. Second, there may be more complex

non-linear relationships between logistics performance and cross-border e-commerce. This paper mainly focuses on linear effects, and future research could further explore threshold effects and moderating effects. Third, the time-dependent relationships between different LPI dimensions have not been fully considered. Subsequent research could use methods such as Bayesian networks to more precisely characterize dynamic impacts. Fourth, this paper focuses on the export perspective, while the impact mechanisms on imports and two-way trade may differ and deserve future attention.

AUTHOR CONTRIBUTIONS

Conceptualization –Tang Yan and Hu Xianman; methodology – Tang Yan and Hu Xianman; investigation – Tang Yan and Hu Xianman; writing-original draft preparation – Tang Yan and Hu Xianman. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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