



## Trade Facilitation Level Measurement and Its Impact on Cross-Border E-Commerce Export Intensity in the Borderlands

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**SUMMARY:** *Economic globalization together with the extensive application of network technology has greatly accelerated the expansion of cross-border e-commerce in border regions, highlighting the practical significance of raising the standard of trade facilitation. This study seeks to assess the influence of trade facilitation on the export performance of cross-border e-commerce in frontier areas and to provide an objective evaluation of the level of trade facilitation across Chinese provinces. Four dimensions, regulatory environment, protective environment, customs environment, and e-commerce environment, are incorporated into an indicator framework for trade facilitation. An entropy-weight approach is employed to estimate provincial trade-facilitation levels in China from 2001 to 2021. The global Moran's I index is then used to examine temporal evolution and spatial distribution patterns, while the entropy method is further applied to determine indicator weights. At the same time, the FE fixed-effects model, together with bilateral trade costs, is used to identify how trade facilitation affects cross-border e-commerce exports in China's border regions. The empirical findings indicate that the overall level of trade facilitation in China has been rising steadily and in a favorable direction. Meanwhile, significant positive spatial agglomeration is observed, as reflected in a global Moran's I value of 0.552. The results also show that every 1% increase in trade facilitation raises cross-border e-commerce exports in border regions by 0.825%, with bilateral trade costs playing an important mediating role. This study enriches the existing literature and provides more precise policy guidance for promoting the growth of cross-border e-commerce in frontier regions.*

**KEYWORDS:** *entropy method; global Moran index; fixed effects model; robustness test; intermediary mechanism; trade facilitation*

## 1 Introduction

Due to the loss of conventional trade, cross-border e-commerce has grown rapidly. This is mostly because cross-border e-commerce's high efficiency and cheap cost make it possible for consumers to purchase internationally without ever leaving their own country, while also promoting globalization. The internal market environment with regard to this aspect is becoming more standardized and systematic as a result of China's successive introduction of various policies pertaining to cross-border e-commerce, which significantly contributes to the sustainable development of cross-border e-commerce [1, 2]. Additionally, China's recent government backing has significantly accelerated the process. The creation of extensive pilot zones for international e-commerce is the most noteworthy of all those measures. In order to assist the future growth of cross-border e-commerce, this program seeks to give cross-border

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e-commerce businesses better service and more robust institutional backing. Businesses will considerably profit from the creation of such pilot zones in terms of cost reduction, increased productivity, and access to international markets [3]. According to data from 2024, China has set up 178 extensive cross-border e-commerce pilot zones in 31 provinces, which is a crucial foundation for the industry's future growth [4].

Globally, Internet technology has flourished as a result of the IT revolution. In light of the aforementioned circumstances, cross-border e-commerce has emerged as a significant use of IT technology in global business. Specifically, it has emerged as one of the most important avenues for the growth of China's international commerce [5]. The restrictive effect of the tariff barrier, which once played a significant role in international commerce, is currently diminishing along with the rapid expansion of international digital trade. However, "trade inefficiency" has evolved into a kind of covert obstacle to the growth of global commerce [6]. Many nations have taken steps to improve the ease and efficiency of commerce in order to further encourage international trade. There are several obstacles that keep cross-border e-commerce from thriving despite the continual advancement of IT technology, which significantly aids in its rapid expansion. These constraints include ineffective customs processing, inadequate logistical distribution, unfinished infrastructure construction, and difficulties making cross-border payments.

The issue of cross-border e-commerce is gaining attention, but more academics are starting to concentrate on the factors that led to its growth. In essence, trade facilitation is the use of technology or policy changes intended to encourage international business activities. This can be accomplished primarily by streamlining and improving the efficiency of the procedures involved in international transactions [11, 12]. With globalization in full swing, trade facilitation has grown in importance as a technique that many countries utilize to encourage trade expansion. Improved trade facilitation will undoubtedly boost cross-border e-commerce's export possibilities and provide useful support for further research on the topic, as it may be seen as a new kind of traditional trade.

#### (1) Research on Trade Facilitation

In response to long-standing issues with international commerce, including complex trade regulations, onerous customs processes, and high transaction costs, Nordic nations initially proposed trade facilitation as a policy concept in the 1950s [13]. With globalization picking up speed after the 1990s, trade facilitation began to garner sustained scholarly attention and eventually emerged as a crucial topic in multilateral trade and economic cooperation, particularly with the support of regional and international economic organizations.

With respect to the measurement of trade facilitation, previous studies have developed various indicator systems. Wilson et al. (2005) were among the earliest scholars to construct a framework for measuring trade facilitation. Their framework included four dimensions, namely port efficiency, customs environment, regulatory environment, and e-commerce, and it was later employed to quantitatively examine the influence of trade facilitation on GNP in APEC economies through a trade gravity model [14]. Toševska and Tevdovski (2016) selected 12 trade-facilitation measures from a broader set of 78 variables and built an evaluation system to assess their effects on economic and trade performance in the SEE region; they also applied a gravity model to estimate the corresponding effects on trade volume [15]. Sakyi et al. (2017) measured trade facilitation by constructing three indicators associated with trade costs, export costs, and import costs with the aid of principal component analysis, and then explored its relationship with economic growth by using a dynamic system generalized method of moments approach [16]. Safaeiamesh and Jenkins (2020) focused on the trade-cost-reduction function of trade facilitation by examining factors such as freight transfer efficiency, document requirements, and customs-clearance time, and ultimately concluded that trade facilitation can

improve overall welfare within a regional economic system [17].

Among empirical approaches, the gravity model has long remained the leading analytical framework in studies of trade facilitation. As a classical tool for analyzing spatial interaction, it is widely regarded as suitable for identifying patterns of trade interaction. Du and Cao (2019) developed a comprehensive evaluation framework for trade facilitation and, on the basis of an extended gravity model, analyzed panel data from 20 countries between 2010 and 2015. Their findings showed that trade facilitation level, gross domestic product, land area, geographic distance, and population size all play important roles in determining China's export trade [18]. Using an augmented gravity model, Host et al. (2019) examined the relationship between trade facilitation and international trade among 150 countries from 2007 to 2016 and found that stronger trade facilitation promotes trade growth, with particularly notable effects in the logistics sector [19]. Zhongxiu and Shabuzh (2020) likewise adopted the gravity model to explore the connection between trade facilitation and import flows, and employed bootstrap and factor analysis to construct an index system for trade facilitation [20]. More recently, Zhang et al. (2023) built an indicator framework for trade facilitation and used the gravity model to assess its effect on agricultural exports. Their results suggested that trade facilitation significantly stimulates such exports, with finance, e-commerce, customs efficiency, and infrastructure development identified as the most influential dimensions [21].

#### (2) Related Research on Cross-border E-commerce

Cross-border e-commerce has attracted broad scholarly attention because of its expanding importance in the global economy when compared with conventional international trade. Much of the earlier literature approached the current challenges and development paths of this field through qualitative analysis. Kawa and Zdrenka (2016) broadened the concept of cross-border e-commerce by introducing the idea of cross-border e-commerce integrators, arguing that these actors can generate economies of scale, reduce transportation costs in cross-border transactions, and strengthen the effectiveness of continuous international operations [22]. Wang et al. (2017) demonstrated through transaction-cost analysis and comparative-advantage modeling that cross-border e-commerce contributes positively to the growth of China's international trade, although this effect becomes weaker under conditions of poor policy implementation and downturns in international trade [23]. Cross-border e-commerce transactions depend heavily on trust between buyers and sellers. Cui et al. (2019) argued that reciprocal trust is a prerequisite for successful transactions, and that breakdowns in trust mechanisms can generate inefficiency, suspicion, and distrust, all of which weaken transaction outcomes [24]. Ye et al. (2021) found that cross-border e-commerce platforms significantly help exporters connect with overseas consumers and improve export performance. Based on data from more than 1,500 Chinese exporters registered on Alibaba's international platform [25], the study showed that platforms such as South America B2B cross-border e-commerce platforms, as discussed by Carvalho et al. (2022), contribute to lowering firms' search costs when seeking partners, and that the use of such platforms can boost firms' overall exports, especially for small enterprises or those with limited digital visibility [26].

#### (3) Research related to trade facilitation and cross-border e-commerce

A growing body of research has confirmed that trade facilitation is a central driver in promoting traditional trade. Even so, because cross-border e-commerce represents an emerging extension of trade, it may not respond in exactly the same way, and therefore the relationship between trade facilitation and cross-border e-commerce still requires more empirical verification. Li (2020) established a trade-facilitation evaluation framework composed of four primary dimensions, infrastructure, regulations, customs-clearance environment, and e-commerce, together with 12 secondary indicators, and then applied an extended gravity model to panel data from 2009 to 2018. The results indicated that trade facilitation exerts a significant

positive influence on China's cross-border e-commerce exports [27]. Liang et al. (2021) further showed that trade facilitation contributes to the expansion of cross-border exports by applying a dynamic panel model, and concluded that the effect is more evident in infrastructure and logistics quality, which are key elements in this field [28]. Zou discovered, through a fixed-effects model, that trade facilitation displays clear regional heterogeneity and substantially increases export intensity in China's cross-border e-commerce sector. Greater trade facilitation, in particular, is associated with stronger performance in eastern areas. This trend appears to be linked to foreign investment, openness, multi-region design, and government support [29]. Using a difference-in-means approach, Wang et al. (2025) examined how trade facilitation shapes cross-border e-commerce trade and found that it can promote the sustainability of cross-border e-commerce development, especially in economically advanced regions [30].

Frontier provinces continue to show clear discrepancies in the export intensity of cross-border e-commerce when compared to coastal areas, therefore enhancing trade facilitation is still crucial to removing current trade obstacles in those areas. In light of this, the current study develops a methodical analytical framework to examine the ways in which trade facilitation affects the export intensity of cross-border e-commerce in frontier regions. In order to calculate indicator weighting objectively, trade facilitation is first measured using the entropy approach. In order to investigate the geographical correlation of trade facilitation and its sub-indicators and determine whether there is spatial autocorrelation in trade-facilitation levels, the global Moran index is then introduced. The variables are then subjected to several covariance tests and descriptive statistical analysis to minimize any potential interference brought on by outliers. In the end, the fixed-effects model is chosen based on the Hausman test. Stepwise regression and the study's independent variables are then gradually eliminated in accordance with the pertinent test findings. The impact of trade facilitation is then experimentally examined once bilateral trade is included as a mediating variable to investigate if an indirect effect exists within the overall effect.

## 2 Measurement of the level of trade facilitation

Although many approaches have been proposed for measuring trade facilitation, each has its own strengths and limitations. For instance, the weighted-sum method is straightforward and easy to implement, yet when indicator values fluctuate sharply, the evaluation results produced by this approach may be hard to define in a rational way. In contrast, the entropy method can reduce bias caused by human judgment by objectively assigning weights to trade-facilitation indicators for comprehensive evaluation, making the results more objective and more suitable for assessing and calculating the indicators included in the trade-facilitation evaluation system for trade-partner countries in border areas. This, in turn, helps reflect the contribution of different indices to trade facilitation more effectively. Therefore, this paper adopts the entropy method to construct and measure the assessment system of trade-facilitation capacity so that abstract concepts can be transformed into specific and quantifiable variables, thereby facilitating the analysis of how the level of trade facilitation in border areas affects the intensity of cross-border e-commerce exports from the frontier region from an empirical perspective.

### 2.1 Construction of a trade facilitation indicator system

Table 1 illustrates how the opinions of earlier researchers have been integrated in this study with regard to the use of secondary indicators for creating an assessment system for trade facilitation. The regulatory environment, port performance, customs environment, and e-commerce are examples of first-order indicators.

Table 1: Trade facilitation evaluation index system

Primary indicator	Secondary indicator	Index attribute
Regulatory environment	Judicial independence	Forward
	Government control	Forward
	Dispute treatment	Forward
	Government transparency	Forward
Port efficiency	Quality traffic	Forward
	Trade window quality	Forward
Customs environment	Unconventional payment	Forward
	Trade system	Forward
	Customs load	Forward
Electricity	New skills are available	Forward
	Available finance	Forward
	Financial support	Forward

## 2.2 Calculation of trade facilitation indicators

In this study, the entropy method is employed to construct the original data matrix and to assign weights objectively to the trade-facilitation indicator system, as shown below:

$$A = \begin{pmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & X_{ij} & \vdots \\ X_{n1} & \cdots & X_{nm} \end{pmatrix}_{n \times m} \quad (1)$$

The  $i$  scheme in this paper represents the  $i$ th country among the trade-partner countries along the route, and the  $j$ th indicator denotes the  $j$ th second-level indicator in the trade-facilitation evaluation system, where  $i = 1, 2, 3 \dots n$ ;  $j = 1, 2, 3 \dots m$ . The Global Competitiveness Report states that all of the chosen secondary indicators have favorable characteristics, with ratings ranging from 1 to 7.

The entropy value method calculates the proportion of a certain indicator in each program to the total number of values of the same indicator, which does not have the influence of the scale and does not need to standardize the data. In addition, it is necessary to level the data in order to prevent the generation of meaningless logarithms when seeking entropy values:

For larger and larger indicators:

$$X'_{ij} = \frac{X_{ij} - \min(X_{1j}, X_{2j}, \dots, X_{nj})}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 1, i = 1, 2, \dots, n; j = 1, 2, \dots, m \quad (2)$$

For smaller and smaller indicators:

$$X'_{ij} = \frac{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - X_{ij}}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 1, i = 1, 2, \dots, n; j = 1, 2, \dots, m \quad (3)$$

For convenience, the non-negativized data are denoted by  $X_{ij}$ .

(1) First, calculate the weight of the  $i$ th scheme under the  $j$ th indicator:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}} (j = 1, 2, \dots, m) \quad (4)$$

(2) Next, compute the entropy value of the  $j$ th indicator:

$e_j = -k * \sum_{k=1}^n P_{ij} \log(P_{ij})$ , where  $k > 0$ ,  $\ln$  denotes the natural logarithm, and  $e_j \geq 0$ . The constant  $k'$  in the formula is related to the sample size  $m$ , and is commonly defined as:

$$k = 1/\ln m, \text{ then } 0 \leq e \leq 1 \quad (5)$$

(3) Compute the coefficient of variation for the  $j$ th indicator:

Then, calculate the coefficient of variation for the  $j$ th indicator, For the  $j$ th indicator, a larger difference in the indicator value  $X_{ij}$  implies a stronger contribution to the overall evaluation and corresponds to a smaller entropy value.

$g_j = 1 - e_j$ , Thus, the larger  $g_j$  is, the more important the indicator becomes.

(4) Finally, determine the indicator weights:

$$W_j = \frac{g_j}{\sum_{j=1}^m g_j}, j = 1, 2, \dots, m \quad (6)$$

The entropy method is then applied to calculate the weight assigned to each trade-facilitation indicator, with the results reported in Table 2. Among the first-level indicators, “Regulatory Environment” receives the largest weight (0.4028). Across all second-level indicators, “Dispute Handling” under the regulatory-environment dimension has the highest weight (0.3102).

Table 2: Trade facilitation index weight

Primary indicator	Weight	Secondary indicator	Weight	Composite weight
Regulatory environment	0.4028	Judicial independence	0.2841	0.1144
		Government control	0.2203	0.0887
		Dispute treatment	0.3102	0.1249
		Government transparency	0.1837	0.0740
Port efficiency	0.2005	Quality traffic	0.3577	0.0717
		Trade window quality	0.6423	0.1288
Customs environment	0.2431	Unconventional payment	0.4351	0.1058
		Trade system	0.1337	0.0325
		Customs load	0.4312	0.1048
Electricity	0.1536	New skills are available	0.2845	0.0437
		Available finance	0.3514	0.0540
		Financial support	0.3641	0.0559

## 2.3 Analysis of trends in trade facilitation and its sub-indicators

### 2.3.1 Analysis of overall developments in trade facilitation

By employing indicators designed to measure trade facilitation together with the entropy method, this paper evaluates trade facilitation and the composite indices of its sub-dimensions for 2001–2021. Table 3 presents the composite trade facilitation index for Chinese provinces over 2001–2021. The results indicate that, except for a few provinces such as Xinjiang and Tibet, the trade facilitation level in most provinces has risen year by year, with particularly notable growth in Guangdong Province, Shanghai Municipality, Jiangsu Province, and Chongqing Municipality. During 2001–2008, the average growth rate of trade facilitation in China was relatively high. Over the period 2009–2012, trade facilitation in China still displayed an overall fluctuating upward trend, but the growth rate slowed markedly, which may be attributed to the impact of the financial crisis on trade facilitation development. This impact caused trade facilitation to decline in certain individual years and reduced the growth rate during 2009–2012. In other words, the financial crisis appears to have constrained the development of trade facilitation, leading both to year-specific declines and to a general slowdown in growth throughout that period.

*Table 3: The comprehensive index of trade facilitation in the provinces*

Region	2001	2005	2009	2013	2017	2021	Mean
Guangdong province	0.2744	0.4112	0.5159	0.6508	0.7500	0.7913	0.2744
Shanghai	0.2276	0.4973	0.6070	0.6515	0.7148	0.7558	0.2276
Jiangsu	0.2634	0.4090	0.5258	0.6718	0.6818	0.7695	0.2634
Zhejiang province	0.2851	0.4675	0.4444	0.5113	0.5781	0.6741	0.2851
Chongqing	0.1960	0.3625	0.4832	0.5530	0.5754	0.7086	0.1960
Shandong	0.2194	0.3095	0.4863	0.5241	0.5987	0.6771	0.2194
Tianjin	0.2455	0.3746	0.4457	0.5562	0.6239	0.5551	0.2455
Beijing	0.2167	0.3732	0.4607	0.5123	0.5811	0.6937	0.2167
Henan	0.2012	0.2468	0.5021	0.5114	0.5299	0.5450	0.2012
Fujian	0.2788	0.3911	0.3759	0.4419	0.5006	0.5061	0.2788
Anhui	0.1937	0.2739	0.4510	0.4947	0.5460	0.6104	0.1937
Hubei	0.1388	0.2610	0.4493	0.4892	0.5678	0.5997	0.1388
Hunan province	0.2200	0.2731	0.4013	0.3865	0.4394	0.5398	0.2200
Liaoning	0.1598	0.3018	0.3764	0.3612	0.3876	0.4634	0.1598
Jiangxi	0.1535	0.2278	0.4190	0.3711	0.4315	0.5581	0.1535
Sichuan	0.2243	0.2970	0.3573	0.3410	0.4254	0.5079	0.2243
Hebei	0.2289	0.2715	0.3685	0.3478	0.3673	0.4593	0.2289
Jilin	0.1271	0.2222	0.3560	0.3004	0.3610	0.3503	0.1271
Guangxi	0.1919	0.2588	0.3875	0.3768	0.3400	0.3382	0.1919
Guizhou	0.1861	0.2349	0.3634	0.2741	0.3765	0.4489	0.1861
Shaanxi province	0.1472	0.1616	0.2579	0.3357	0.4114	0.4297	0.1472
Heilongjiang	0.1324	0.1937	0.2939	0.3037	0.3095	0.4040	0.1324
Hainan province	0.1865	0.2171	0.2343	0.3283	0.3057	0.3619	0.1865
Shanxi Province	0.0926	0.1820	0.2860	0.3583	0.3928	0.3588	0.0926
Inner Mongolia	0.1201	0.1965	0.2799	0.3517	0.3465	0.3431	0.1201
Qinghai province	0.2387	0.2243	0.3212	0.2541	0.3004	0.3183	0.2387
Yunnan province	0.1500	0.1944	0.3035	0.2392	0.2268	0.4033	0.1500
Ningxia	0.0625	0.1590	0.2324	0.1840	0.3092	0.3653	0.0625
Gansu	0.1500	0.1271	0.1972	0.1598	0.3295	0.3249	0.1500
Xinjiang	0.0863	0.2229	0.2273	0.3111	0.2017	0.2950	0.0863
Tibet	0.0040	0.0189	0.0687	0.2988	0.1764	0.1341	0.0040
National average	0.1807	0.2698	0.3703	0.4017	0.4415	0.4933	0.1807

### 2.3.2 Analysis of trends in trade facilitation sub-indicators

Additionally, Table 4 shows the composite score of each Chinese province's regulatory environment from 2001 to 2021, using the sub-scores of the regulatory environment indicators as an example. The data shown in the above table makes it evident that, between 2001 and 2021, the regulatory environment in practically every province in China has significantly improved; however, the degree of improvement varies greatly between provinces. Among them, the regulatory environment in Jiangsu Province, Guangdong Province, Beijing Municipality, and Tibet Autonomous Region is in a state of growth, except for some years, and the growth rate is large. The growth of the regulatory environment in Henan, Hebei, Shaanxi, Guangxi Zhuang Autonomous Regions and Jilin Provinces fluctuates, with no significant growth or decline. The regulatory environment in Tianjin, Xinjiang Uygur Autonomous Region and Hainan Province is growing overall, but the growth rate is small.

*Table 4: The comprehensive index of provincial regulation environment*

Region	2001	2005	2009	2013	2017	2021	Mean
Guangdong province	0.1163	0.0891	0.2552	0.7131	0.8142	0.7207	0.4514
Shanghai	0.1127	0.3119	0.2018	0.4319	0.7792	0.7862	0.4373
Jiangsu	0.1232	0.2973	0.4467	0.5497	0.7120	0.8297	0.4931
Zhejiang province	0.2509	0.1041	0.1608	0.4702	0.6106	0.6541	0.3751
Chongqing	0.1365	0.1920	0.3961	0.3768	0.5864	0.5481	0.3727
Shandong	0.3070	0.2979	0.4915	0.5248	0.4507	0.2759	0.3913
Tianjin	0.2183	0.3507	0.1352	0.3443	0.3616	0.5612	0.3286
Beijing	0.2866	0.3599	0.4972	0.3033	0.4878	0.4506	0.3976
Henan	0.3633	0.2526	0.4931	0.2893	0.3032	0.6307	0.3887
Fujian	0.3417	0.1179	0.4008	0.3496	0.5111	0.5226	0.3740
Anhui	0.0845	0.3141	0.4656	0.5210	0.5514	0.4742	0.4018
Hubei	0.3212	0.3330	0.4565	0.4225	0.2884	0.1943	0.3360
Hunan province	0.2804	0.1297	0.2065	0.4805	0.4643	0.3433	0.3175
Liaoning	0.1087	0.0689	0.5399	0.2789	0.2832	0.5867	0.3111
Jiangxi	0.0474	0.1063	0.5272	0.5563	0.6345	0.5000	0.3953
Sichuan	0.2842	0.3501	0.5183	0.5231	0.3320	0.2732	0.3802
Hebei	0.2247	0.2179	0.3479	0.3458	0.3472	0.5314	0.3358
Jilin	0.1780	0.1488	0.2921	0.4244	0.5195	0.4954	0.3430
Guangxi	0.2741	0.1085	0.3232	0.4283	0.4820	0.3267	0.3238
Guizhou	0.1301	0.2506	0.4508	0.2198	0.3536	0.2380	0.2738
Shaanxi province	0.2757	0.1687	0.4109	0.3200	0.3783	0.5005	0.3424
Heilongjiang	0.0878	0.1007	0.3064	0.5056	0.5683	0.3153	0.3140
Hainan province	0.2533	0.1167	0.1969	0.2525	0.4939	0.3747	0.2813
Shanxi Province	0.1598	0.2385	0.4082	0.2678	0.2511	0.5443	0.3116
Inner Mongolia	0.1013	0.3110	0.2625	0.5089	0.2430	0.5555	0.3304
Qinghai province	0.0794	0.1466	0.2496	0.2703	0.3127	0.2640	0.2204
Yunnan province	0.2292	0.1823	0.2186	0.2652	0.5941	0.3627	0.3087
Ningxia	0.1168	0.1295	0.2578	0.1766	0.3055	0.4523	0.2398
Gansu	0.1790	0.3160	0.3462	0.5652	0.3067	0.3791	0.3487
Xinjiang	0.0744	0.0782	0.2288	0.4904	0.3789	0.3315	0.2637
Tibet	0.2177	0.1478	0.1917	0.3874	0.3115	0.3155	0.2619
National average	0.1924	0.2044	0.3447	0.4053	0.4522	0.4625	

## 2.4 Characteristics of the spatial distribution of trade facilitation and its sub-indicators

### 2.4.1 Characteristics of the spatial distribution of trade facilitation

This research will investigate the geographical correlation pattern of trade facilitation based on the composite index of trade facilitation. The worldwide Moran Index is used to investigate the spatial correlation of trade facilitation in China; the outcome is shown in Fig. 1. Figure 1 shows that the worldwide Moran Index value is positive, or 0.552, suggesting that the degree of trade facilitation in China's provinces is spatially clustered.

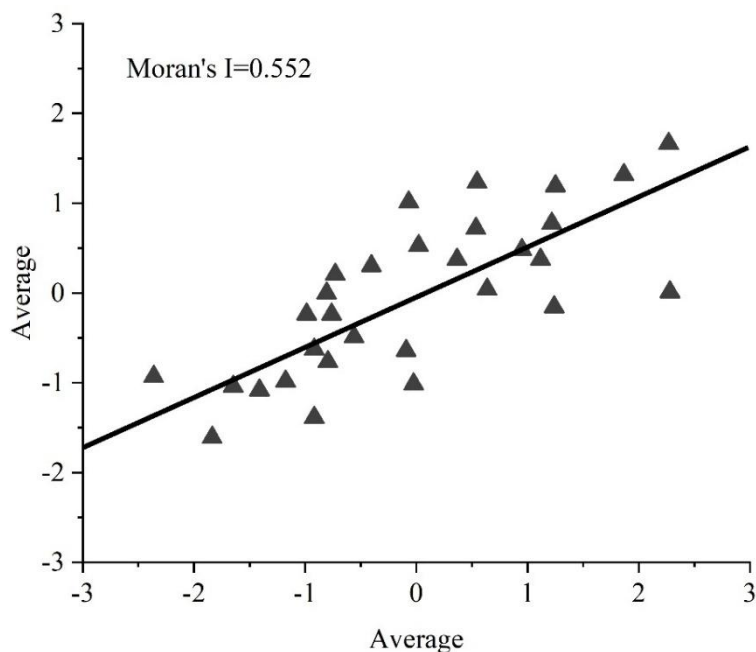


Figure 1: Moran point diagram of trade facilitation mean

### 2.4.2 Characteristics of the spatial distribution of trade facilitation sub-indicators

According to the comprehensive index of the regulatory environment, this paper draws the spatial correlation analysis map of the regulatory environment. Figure 2 shows the spatial correlation test map of China's regulatory environment. Observing the values in the map, it can be seen that the global Moran index is positive, with a magnitude of 0.154, which indicates that there is a spatial agglomeration effect in the regulatory environment of China's provinces, but the spatial agglomeration effect is weak.

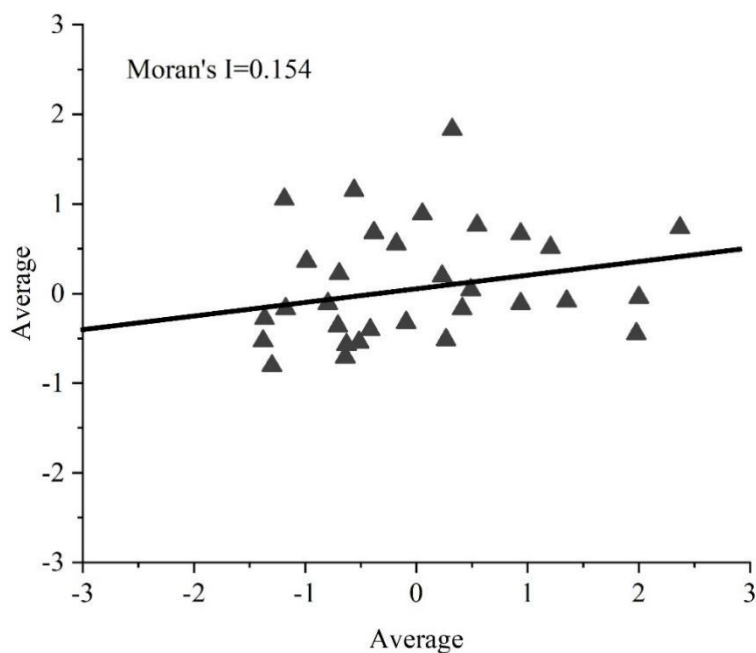


Figure 2: Moran scatter diagram of the mean of the regulatory environment

According to the comprehensive index of port efficiency, this paper draws the spatial correlation analysis map of port efficiency. Figure 3 shows the spatial correlation test map of China's port efficiency. Observing the values in the map, it can be seen that the global Moran's index is positive with a magnitude of 0.385, which indicates that there is a spatial clustering effect in the port efficiency of China's provinces.

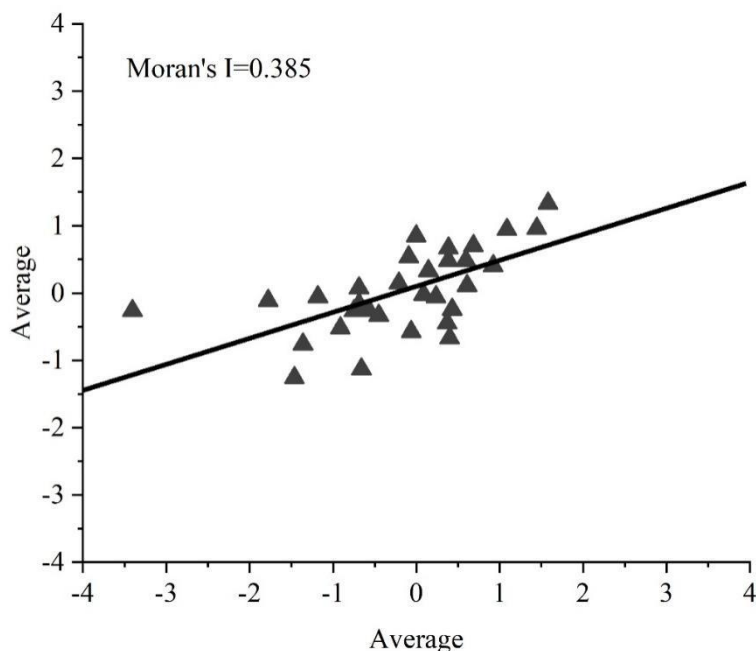


Figure 3: Spatial correlation test of national port efficiency

According to the comprehensive index of customs environment, this paper draws the spatial correlation analysis map of customs environment. Figure 4 shows the spatial correlation test map of China's customs environment. Observing the values in the map, it can be seen that the global Moran index is positive, with a magnitude of 0.167, which indicates that there is a spatial

clustering effect in the customs environment of China's provinces, but the clustering effect is weak.

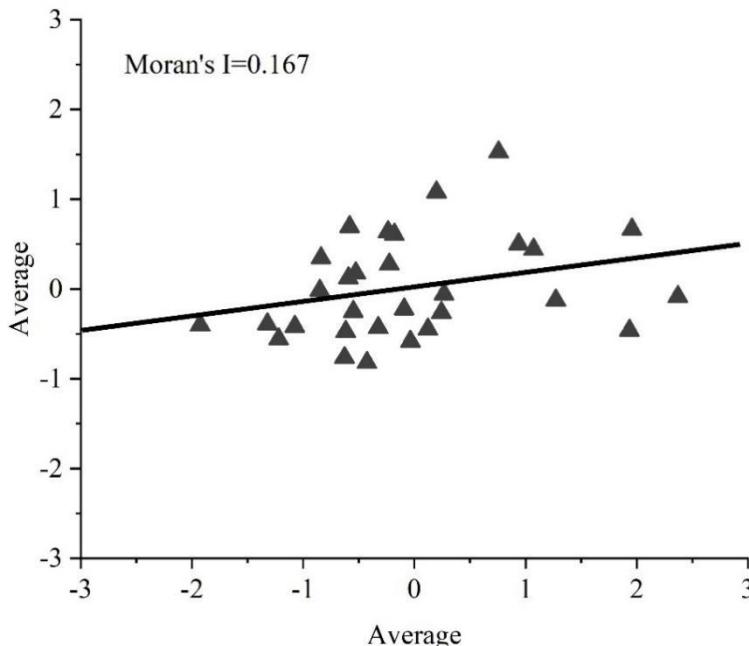


Figure 4: Spatial correlation survey of customs in the country

According to the comprehensive index of e-commerce and digital utilization, this paper draws the spatial correlation analysis map of e-commerce. Figure 5 shows the spatial correlation test map of e-commerce in China. Observing the values in the map, it can be seen that the global Moran index is positive with a magnitude of 0.274, which indicates that there is a spatial agglomeration effect of e-commerce in Chinese provinces, but the spatial agglomeration effect is relatively weak.

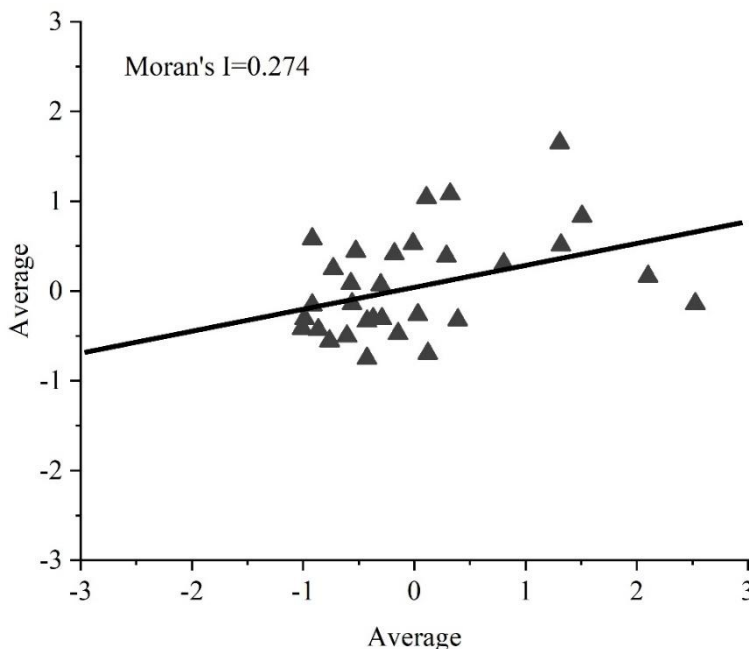


Figure 5: The spatial correlation test of national e-commerce

### 3 Empirical Study on Trade Facilitation Influencing Cross-border E-commerce Exports in Borderlands

#### 3.1 Modeling

The economic size and total population of the borderland are removed from the regression analysis since this study looks at how trade facilitation affects the export intensity of cross-border e-commerce in border regions. Distance was also often considered a significant feature in model creation in earlier trade research. Nonetheless, the growth of international e-commerce can lessen the limitations of conventional trade and improve the convenience of product distribution to target markets. Furthermore, the phrase "geographic distance" between two nations is predefined. Such a constant factor is automatically eliminated during estimate when a fixed-effects model is used. Geographic distance is therefore excluded from the model formulation. Additionally, Internet development is critical to cross-border e-commerce. In most cases, model creation should take into account the exporting nation's level of Internet development. However, no additional variables of this type are presented independently in this study because the trade-facilitation index already incorporates the indicators used to define e-commerce progress. A number of variables are converted to logarithmic form in order to lessen the potential impact of heteroskedasticity. Based on this, the model used in this work is described as follows:

$$\ln IEX_{it} = \alpha_0 + \alpha_1 \ln TFI_{it} + \alpha_2 \ln GDP_{it} + \alpha_3 \ln POP_{it} + \alpha_4 \ln TAR_{it} + \varepsilon_{it} \quad (6)$$

In Eq. (6),  $IEX_{it}$  represents the intensity of cross-border e-commerce exports from border area  $t$  to country  $i$  in year  $t$ .  $TFI_{it}$  denotes the trade-facilitation index of country  $i$ , reflecting its level of trade facilitation.  $GDP_{it}$  stands for the gross domestic product of country  $i$  in year  $t$ , representing its level of economic development.  $POP_{it}$  denotes the total population of country  $i$  in year  $t$ , reflecting market size.  $TAR_{it}$  denotes the trade-weighted average tariff rate of country  $i$ , which represents its tariff level.  $\alpha_0$  is a constant term,  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$ ,  $\alpha_4$  are the coefficients of the explanatory variables, and  $\varepsilon_{it}$  is the random disturbance term.

#### 3.2 Sources of variables and data

The variables used in this study include cross-border e-commerce export volume (IEX), trade facilitation index (TFI), GDP of the exporting country, population (POP), weighted average tariff rate (TAR), and bilateral trade cost (COST). These variables are calculated on the basis of the model developed above.

(1) Measurement of cross-border e-commerce export value. In this paper, the calculation follows the formula most frequently adopted in the existing literature:

$$IEX_{it} = \text{China's cross-border e-commerce export scale in period } t \\ * \frac{\text{China's export trade with country } i \text{ in period } t}{\text{China's total export trade in period } t} \quad (7)$$

The data used for the scale of China's cross-border e-commerce exports come from Wind, and the other two trade data come from the CEIC statistical database. Among them, in order to

unify the unit of measurement, the scale of China's cross-border e-commerce exports is converted in accordance with the exchange rate of the year to get the dollar-denominated data.

(2) Determination of trade facilitation index. The calculation results in Chapter 2 are directly selected.

(3) The export destinations' GDP, POP, and trade-weighted average tax rate (TAR) are calculated. The Global Competitiveness Report and China's National Bureau of Statistics are the sources of the data.

The model variables and data sources are specifically shown in Table 5.

*Table 5: Variable data source*

	Variable name	Expectation coefficient symbol	Data source
Dependent variable	IEX		Central meridian statistics
Core variable	TFI	+	The previous article is in the calculation
Mediation variable	COST	-	Calculation calculation
Control variable	GDP	+	China national bureau of statistics
	POP	+	China national bureau of statistics
	TAR	-	Global competitiveness report

### 3.3 Descriptive statistics and model testing

#### 3.3.1 Descriptive statistics

It is crucial to determine whether the selected data collection is comparable and amenable to analysis before beginning the empirical investigation. In particular, all variables in this study, aside from the tariff variable, are converted logarithmically. Descriptive statistics are then performed on the transformed data set, and the results are shown in Table 6 below. The descriptive statistics above show that the selected data set does not appear to include any outliers. Additionally, the amount of the data is not very different, which makes data analysis fairly feasible.

*Table 6: Descriptive statistics*

Variable	Observed value	Mean	Standard deviation	Minimum value	Maximum value
LnIEX	111	1.625	1.574	-3.745	2.002
LnTFI	118	0	0.623	-2.003	0.694
LnGDP	118	56845	2.215	4.65	13.815
LnPOP	118	150050	1.884	6.005	14.123
TAR	95	2.734	0.685	0	2.456

#### 3.3.2 Correlation test

The results of the correlation analysis performed on the chosen data in this section are shown in Table 7. There is no strong inter-correlation because the majority of the correlation values between the variables are less than 0.5. Examining the correlation values in the first column, it is evident that both countries' populations, GDPs, and trade facilitation contribute significantly to cross-border e-commerce exports; however, despite being positive (0.132), the tariff coefficient is not significant.

Table 7: Correlation test results

	LnIEX	LnTFI	LnGDP	LnPOP	TAR
LnIEX	1				
LnTFI	0.298***	1			
LnGDP	0.735***	0.004	1		
LnPOP	0.336***	-0.056	0.968***	1	
TAR	0.132	-0.279***	0.115	0.148	1

### 3.4 Empirical results and analysis

#### 3.4.1 Model selection and analysis of regression results

To determine the most appropriate model, a series of model tests are first carried out. Table 8 indicates that the fixed-effects model performs substantially better than the hybrid-effects model, with  $F(85,776)=32.511$  and  $p=0.000$ . The BP test further suggests that the random-effects model is clearly superior to the mixed-effects model. According to the Hausman test, the fixed-effects model is preferred over the random-effects model, with  $\chi^2(6)=11.554$  and  $p=0.072$ . Since  $p>0.1$ , the fixed-effects model is ultimately adopted as the final specification.

Table 8: Model test results

Test type	F test	BP test	Hausman test
Inspection purpose	FE model and hybrid model comparison selection	The RE model and the hybrid effect model are more selective	The FE model and the RE model are more selective
Test value	$F(85,776)=32.511$ , $p=0.000$	$X^2(1)=1475.369$ , $p=0.000$	$X^2(6)=11.554$ , $p=0.072$
Test conclusion	FE model	RE model	FE model

Meanwhile, the benchmark regression results are reported in Table 9 after an overall comparison among the mixed-effects, random-effects, and fixed-effects models. The table shows that the estimated coefficient of the key explanatory variable TFI, which measures the extent of trade facilitation, is significantly positive at the 1% level. This indicates that stronger trade facilitation between two countries substantially increases the volume of cross-border e-commerce exports from China's border regions.

In addition, the variance inflation factor (VIF) test is used to check whether multicollinearity affects model estimation, since this issue is typically important in correlation analysis. The results show that every variable has a VIF value below 2, which is well under the critical threshold of 10 and therefore suggests that serious multicollinearity is absent. This means that the model estimated in this paper does not suffer from a multicollinearity problem. For simultaneous regressions, both the fixed-effects model and the mixed-effects model are employed.

*Table 9: Benchmark regression results*

Variable	Mixing effect	VIF	RE	FE
LnTFI	0.825***	1.65	5.305***	7.405***
	0.335		0.826	1.023
LnGDP	0.0254***	1.43	0.0185	0.0162
	0.0074		0.0213	0.0205
LnPOP	1.534***	1.25	-0.533	-1.178
	0.369		0.726	0.814
TAR	-0.405***	1.16	-0.268	0.0113
	-0.0846		0.195	0.245
Constant	26.35***	1.11	31.15***	29.55***
	1.112		1.413	1.772
Observations	800		800	800
R <sup>2</sup>	0.675			0.54

Once more, the Hausman test demonstrates that the model used in this investigation is appropriate for the fixed effects approach. This study uses the stepwise regression technique to estimate the coefficients in order to perform an initial test on the model's robustness and prevent any interference between variables. Table 10 displays the regression findings. The signs and significance levels of coefficients for the primary variable, which is the degree of trade facilitation, do not change even after progressively lowering the number of control variables. This is first proof of the model's resilience.

The stepwise regression model's findings indicate that the trade facilitation coefficients are still significant at 1%. To put it another way, a rise in trade facilitation is probably going to significantly boost the export volume of cross-border e-commerce in the border regions, confirming the theory. The control variables' coefficients are still not significant.

*Table 10: Stepwise regression results*

Variable	(1)	(2)	(3)	(4)
LnTFI	12.44***	7.295***	7.365***	7.441***
	1.185	1.054	1.062	1.085
LnGDP		0.0185	0.0179	0.0174
		0.025	0.0215	0.0215
LnPOP			-0.995	-0.975
			0.844	0.842
TAR				-0.0856
				0.235
Constant	15.23***	32.15***	31.56***	31.63***
	0.531	1.36	1.475	1.498
Observations	800	800	800	800
R <sup>2</sup>	0.25	0.485	0.485	0.493

### 3.4.2 Sub-indicator regression analysis

In this section, the paper further tests several sub-dimension indicators on trade facilitation to explore the impact of the first-level indicators of regulatory environment (Reg), port efficiency (Port), customs environment (Cus), and e-commerce (E-B) on the intensity of cross-border e-commerce exports from the border.

The sub-indicator regression model is as follows:

$$\ln EXP = \alpha + \alpha_1 \ln Reg_{ij} + \alpha_2 \ln GDP_{ij} + \alpha_3 \ln POP_{ij} + \alpha_4 TAR_{ij} + u_i + \varepsilon_{ijt} \quad (8)$$

$$\ln EXP = \alpha + \alpha_1 \ln Port_{ij} + \alpha_2 \ln GDP_{ij} + \alpha_3 \ln POP_{ij} + \alpha_4 TAR_{ij} + u_i + \varepsilon_{ijt} \quad (9)$$

$$\ln EXP = \alpha + \alpha_1 \ln Cus_{ij} + \alpha_2 \ln GDP_{ij} + \alpha_3 \ln POP_{ij} + \alpha_4 TAR_{ij} + u_i + \varepsilon_{ijt} \quad (10)$$

$$\ln EXP = \alpha + \alpha_1 \ln E-B_{ij} + \alpha_2 \ln GDP_{ij} + \alpha_3 \ln POP_{ij} + \alpha_4 TAR_{ij} + u_i + \varepsilon_{ijt} \quad (11)$$

Table 11 reports the regression results for the sub-indicators. According to the estimation results, the coefficients of all core explanatory variables associated with the importing country's regulatory environment are significant in this model, suggesting that the regulatory environment has no correlation with the volume of cross-border e-commerce exports to the frontier within the scope of the samples used in this paper. The estimated coefficient of -0.6452 indicates that the causal relationship between the two cannot be established. This may be because, under the current trade agreement, the importing nation's regulatory framework has not yet exerted a meaningful influence on the volume of cross-border e-commerce exports to it. At more advanced stages of commerce, including outbound investment, greater responsiveness to host-country regulation may become more important.

Regardless of whether related control factors are added, the results remain highly robust, and all explanatory variables are significant and positive at the 1% significance level. At the 1% significance level, the estimated coefficients of port efficiency, customs environment, and e-commerce are all significantly positive. This suggests that good port efficiency, customs environment, and e-commerce conditions can greatly improve the recognition of border cross-border e-commerce products in importing countries and expand the market reach of such products, thereby increasing export scale.

Table 11: Sub-index regression results

	(1)	(2)	(3)	(4)	(5)
LnTFI	7.405***				
	1.0251				
LnReg		-0.6452			
		0.7653			
LnPort			1.425***		
			0.5385		
LnCus				5.415***	
				0.6261	
LnE-B					0.3036***
					0.3453
Constant	29.53***	36.92***	35.78***	27.65***	33.12***
	1.7756	1.6523	1.6635	1.5163	1.5386
F	158.23	142.89	154.87	90.26	145.12
Observations	800	800	800	800	800
R <sup>2</sup>	0.523	0.443	0.455	0.589	0.508
Numbers	89	89	89	89	89

### 3.4.3 Robustness Tests and Endogeneity Discussion

By changing pertinent parameters in the benchmark model and then re-estimating the specification, the robustness test evaluates the dependability of the model estimates. The model's stability can be deemed proven if the estimates generated following parameter substitution stay consistent with the baseline regression. Table 12 presents the robustness check findings.

After re-estimating the model and adjusting the fundamental elements, none of the previous results are altered. The coefficients of TFI, port efficiency, customs environment, and e-commerce are all still statistically significant at the 1% level, despite the projected coefficient of the trade facilitation level being 6.077. These findings suggest that trade facilitation and advancements in associated aspects boost the export scope of cross-border e-commerce in border locations. As a consequence, the robustness test verifies the great stability and dependability of the benchmark regression findings.

Trade facilitation may also be correlated with the volume of cross-border e-commerce exports in border areas. For example, participation in trade activities may strengthen ties between two countries, thereby encouraging the negotiation of RTA agreements and other efforts that improve the facilitation of bilateral commerce. As a consequence, endogeneity may arise in this context because such interaction could operate between trade facilitation and export size. The level of trade facilitation in one period may therefore be associated with export performance in the following period, and two-stage least squares (2SLS) estimation is adopted to address the potential endogeneity issue and to identify the effect of trade facilitation on China's export scale while controlling for possible endogenous disturbance. The estimated coefficients of trade facilitation and all sub-dimensions remain positive, as shown in the data below. This indicates that trade facilitation still exerts a strong favorable influence on export scale once the disturbance is removed. In addition, all first-stage model F-values are greater than the empirical cutoff of 10, showing that the chosen instrumental variables are appropriate for the study. The specific two-stage least-squares estimation results are not presented here because of space limitations.

Table 12: Robustness analysis

Variable	(1)	(2)	(3)	(4)	(5)
LnGDP	0.0165	0.0205	0.016	0.0264*	0.0233*
	0.0132	0.0143	0.0138	0.0126	0.0135
LnPOP	-0.865*	0.0185	-0.175	-0.265	-0.536
	0.506	0.544	0.526	0.478	0.508
TAR	-0.165	-0.095	-0.148	-0.305**	-0.115
	0.146	0.156	0.153	0.138	0.146
sigma_u	1.245***	1.285***	1.175***	1.412***	1.167***
	0.105	0.113	0.103	0.116	0.095
sigma_e	0.532***	0.578***	0.568***	0.493***	0.536***
	0.0134	0.0145	0.0144	0.0123	0.0134
LnTFI	6.077***				
	0.554				
LnReg		-0.0465			
		0.413			
LnPort			1.875***		
			0.362		
LnCus				4.623***	
				0.306	
Constant					3.125***
					0.291
Observations	800	800	800	800	800

### 3.5 Analysis of impact mechanisms

#### 3.5.1 Mediated effects test

This study adopts the standard mediation framework together with the corresponding three-step regression procedure to determine whether bilateral trade costs mediate the effect of trade facilitation on the growth of frontier cross-border e-commerce exports. First, trade facilitation is regressed on export trade in border regions. At this stage, the dependent variable is the value of cross-border e-commerce exports, and the purpose is to test whether trade facilitation promotes the expansion of export-oriented cross-border e-commerce. Second, bilateral trade costs are regressed on trade facilitation. If trade facilitation is found to reduce bilateral trade costs, and if a significant association exists between the two, then the mediation pathway is preliminarily supported. Third, the dependent variable, namely frontier cross-border e-commerce exports, is regressed jointly on trade facilitation and bilateral trade costs after the introduction of the mediator. If bilateral trade cost remains significant in this step, it indicates that by lowering such costs, trade facilitation can contribute to the growth of frontier cross-border e-commerce exports. On the basis of this procedure, the mediation model is specified as follows:

$$\ln EXPT_{ij} = \gamma_0 + \gamma_1 \ln TFI_j + \gamma_2 Control_j + \mu_{ij} \quad (12)$$

$$\ln COST_{ij} = \varphi_0 + \varphi_1 \ln TFI_j + \varphi_2 Control_j + \mu_{ij} \quad (13)$$

$$\ln EXPT_{ij} = \delta_0 + \delta_1 \ln TFI_j + \delta_2 COST_{ij} + \delta_3 Control_j + \mu_{ij} \quad (14)$$

where  $EXPT_{ij}$  denotes the value of cross-border e-commerce exports;  $\ln TFI_j$  refers to the trade facilitation level;  $COST_{ij}$  denotes the bilateral trade cost incurred in conducting trade;  $Control_j$  represents the set of control variables selected in this paper, and  $\mu_{ij}$  is the random error term.

Through the above analysis, the results of this paper's mediation test for bilateral trade costs are presented in Table 13.

The effect of trade facilitation on frontier cross-border e-commerce export growth is reported in column (1). The table shows that each one-percent increase in trade facilitation produces a positive effect on frontier cross-border e-commerce exports, and the estimated coefficient indicates that a 1% rise in trade facilitation leads to a 0.825% increase in export volume in border areas, which is significant at the 1% level. This demonstrates that trade facilitation has a clear positive influence on the expansion of cross-border e-commerce exports.

The effect of trade facilitation on bilateral trade cost is reported in column (2). The table suggests that trade facilitation may considerably reduce bilateral trade expenses. For example, a one-percent rise in trade facilitation is associated with a 0.263% decline in bilateral trade costs, and this result is statistically significant at the 10% level. These findings show that trade facilitation affects the growth of cross-border e-commerce exports partly through its role in lowering bilateral trade costs, and that some of its effects originate from the reduction in such costs.

The results obtained after introducing bilateral trade cost as a mediating variable are reported in column (3). The table indicates that the positive contribution of trade facilitation to

the growth of border cross-border e-commerce exports remains evident even when bilateral trade cost is included as a mediator. However, the estimated coefficient is smaller than before, which supports the mediation interpretation. In this instance, the evidence points to partial mediation, since every 1% improvement in trade facilitation results in a 0.621% rise in bilateral trade costs. Based on the above analysis, it can be concluded that bilateral trade cost serves as a mediating channel through which trade facilitation influences the growth of cross-border e-commerce exports.

Based on the aforementioned study, it can be concluded that bilateral trade costs function as a mediating route for trade facilitation to impact the growth of cross-border e-commerce export trade.

*Table 13: The mediation effect tests the results*

Variable	(1)	(2)	(3)
	LnEXPT	COST	LnEXPT
LnTFI	0.825***	-0.263*	0.621***
	0.335	0.155	0.315
COST			-0.465*
			0.273
LnGDP	0.0254***	-0.075***	0.942***
	0.0074	0.024	0.165
LnPOP	1.534***	0.001	0.015***
	0.369	0.001	0.003
TAR	-0.405***	0.008	-0.017
	-0.0846	0.008	0.0235
Constant	26.35***	-1.654	-7.845
	1.112	1.274	5.678
Observations	800	800	800
R-squared	0.675	0.605	0.791

### 3.5.2 Robustness Tests for Intermediation Effects

This study uses the maximum likelihood estimation approach to analyze the original model in order to assess the reliability of the previously described results. The robustness of the model is then verified by comparing the two regressions. Table 14 below shows the results.

The data shown in Table 14 indicates that, when the original model is re-analyzed using the maximum likelihood estimation method, it is found that, in contrast to the baseline model, the signs of the independent variables, including the intermediary variable, stay constant despite the difference in the magnitude of the regression coefficients. Additionally, the impact of trade facilitation on cross-border e-commerce export trade has a regression coefficient of 0.825, which is statistically significant at the 1% level.

Table 14: Robustness test results

Variable	(1)	(2)	(3)
	LnEXPT	COST	LnEXPT
LnTFI	0.825***	-0.285*	0.615***
	0.335	0.095	0.401
COST			-1.065***
			0.399
LnGDP	0.0254***	-0.065**	0.995***
	0.0074	0.035	0.194
LnPOP	1.534***	0.002	0.015
	0.369	0.003	0.013
TAR	-0.405***	0.003	-0.025
	-0.0846	0.006	0.023
Constant	26.35***	-1.975	-11.025**
	1.112	1.645	6.276
Observations	800	800	800
R-squared	0.675	0.605	0.791

## 4 Conclusion

The main conclusions of this study are derived from the construction of a trade-facilitation indicator framework and from an empirical model designed to investigate how trade facilitation affects cross-border e-commerce export activities in border regions, as well as the mechanisms underlying this relationship.

(1) China's level of trade facilitation has displayed clear spatial variation over the period of analysis, and the differences among provinces have narrowed over time. From 2001 to 2021, most Chinese provinces experienced improvements in trade facilitation, especially Guangdong, Shanghai, and other coastal areas with comparatively advanced trade development, whereas frontier provinces such as Xinjiang and Tibet remained behind. The global Moran index for Chinese provinces is 0.552, indicating the existence of spatial clustering in trade facilitation and highlighting the importance of coordinated interregional progress.

(2) The intensity of cross-border e-commerce exports in China's border regions has increased as trade facilitation has improved. Specifically, a 1% increase in trade facilitation is associated with a 0.825% rise in cross-border e-commerce export volume in border areas, according to the benchmark regression analysis. These empirical findings imply that measures intended to improve port efficiency, customs procedures, and e-commerce-related conditions can significantly expand the export volume of cross-border e-commerce products.

(3) A 1% improvement in trade facilitation reduces bilateral trade costs between two countries by 0.263%, according to the estimates from the mediation analysis. This suggests that lower trade costs, supported by better facilitation, strengthen export growth through an indirect mechanism alongside the direct effect of trade facilitation itself. Accordingly, the results confirm that trade-cost reduction plays a mediating role in the relationship between trade facilitation and cross-border e-commerce export expansion.

In light of the aforementioned findings, it is recommended that various policies be used to ensure appropriate economic growth, such as regional differentiation strategies, attention to intermediate channels, and the implementation of trade facilitation monitoring systems in border regions.

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