

# The Impact of Digital Transformation on International Trade Based on Big Data Analysis Models and Threshold Effects

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**Abstract.** Currently, the world is experiencing a wave of digitalization, and the digital economy has become a significant engine for the growth of import and export trade. This paper deeply analyzes the impact of the digital economy on import and export trade from dimensions such as technology, society, and institutions. Based on panel data from 42 cities in China's three major urban clusters (the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin-Hebei region) from 2011 to 2021, using the mediation effect model, threshold effect model, and K-means clustering algorithm, it examines the impact of digital economic development on import and export trade and its transmission mechanism. The research findings indicate that the development of the digital economy significantly promotes import and export trade; the level of technological innovation plays a mediating role in the relationship between digital economic development and import and export trade; there is a single threshold positive promotion effect of technological innovation level in the process of digital economic development affecting import and export trade; the degree of urbanization exhibits a single threshold effect in the process of digital economic development affecting import and export trade, specifically transitioning from inhibiting to promoting effects once the threshold value of urbanization is surpassed. Furthermore, there is a certain regional heterogeneity in the above conclusions among the three major urban clusters. The research results have certain guiding significance for optimizing the structure of foreign trade, promoting high-quality development of import and export trade, and achieving high-level economic and social development.

**Keywords:** Digital Transformation, Cluster Analysis, Mediation Effect, Threshold Effect, Import and Export Trade.

## 1. Introduction

In October 2022, General Secretary Xi Jinping emphasized in the report of the 20<sup>th</sup> National Congress of the Communist Party of China that the digital economy is becoming a key force in restructuring global factor resources, reshaping the global economic structure, and changing the global competition pattern. In recent years, the development of China's digital economy has continued to accelerate. The "Global Digital Economy White Paper" pointed out that from 2016 to 2022, China's digital economy has maintained rapid growth, with the digital economy scale increasing by \$4.1 trillion, with an average annual compound growth rate of 14.2%. China has developed into the world's second largest digital economy power after the United States. With the development of global economic integration and the penetration of digital technology into trade, international trade has shown new trends such as digitalization, greening, and security. The high-quality development of foreign trade is an important part of China's high-quality economic and social development, and it is an important manifestation of building a strong trading nation. The digital economy has multiple promoting effects on the high-quality development of trade. With its technological innovation effect, the digital economy can reduce trade costs, optimize resource allocation, and transform trade structure. At the same time, the widespread application of digital technologies such as cloud computing, big data, and artificial intelligence in various links of import and export trade has driven the continuous transformation and upgrading of foreign trade. From 2016 to 2022, China's total import and export value has increased from 24.33 trillion yuan to 42.07 trillion yuan, reflecting the high-quality development of China's import and export trade. Based on the evident regional heterogeneity in import and export trade, studying the impact of digital economic development on import and export trade, analyzing the underlying impact mechanisms, and exploring

its regional heterogeneity are of great significance for optimizing foreign trade patterns, promoting high-quality development of import and export trade, and achieving high-quality economic and social development.

## 2. Literature Review

### 2.1. Impact of the Digital Economy on International Trade

American economist Tapscott, in his work *The Digital Economy: Promise and Peril in the Age of Networked Intelligence*, first proposed the concept of the digital economy, considering it a new form of economic development characterized by the internet, big data, cloud computing, and other technological features. Since then, the digital economy has entered the public eye, sparking global scholars' high attention to it. Existing studies generally believe that the digital economy has a positive impact on international trade. B.M. Chivhanga conducted research on 47 economies in Africa, showing that the impact of the digital economy is crucial for driving international trade in Africa in both the short and long term. Li Zhongmin et al. argue that the continuous penetration of digital technology into industries, combined with the trend of industrial integration, has further enhanced the rapid development of China's digital trade. Unlike traditional trade, digital trade significantly reduces transaction costs and improves import and export efficiency. Abeliatsky et al. found in their study of 115 countries and regions that information and communication technology significantly promoted the pattern of trade in goods and services. I. Ahmedov, through research on Uzbekistan, found that the scale and potential of the digital economy and its impact on international trade are immense and growing every day. China's export trade has presented new patterns and trends under the impetus of digital economic development, with new features such as diversified trading entities, networked organizational structures, diverse trade products, and optimized export trade cost structures. Moreover, the digital economy can significantly promote the development of services trade in countries or regions. Research by Yurong Zhu et al. indicates that the digital economy can significantly promote the development of international trade in cities, and its promotion effect on exports is greater than imports. Some scholars have studied the impact of digital economic development on inter-provincial trade. Li Hongbing et al. found that the development of the digital economy can significantly promote inter-provincial trade outflow in their research. Xia Jiechang et al. believe that raising the level of digital economic development in each province can effectively overcome the objective obstacles of administrative and geographical factors, effectively reducing the degree of inter-provincial trade barriers.

### 2.2. Transmission Mechanisms of the Digital Economy on International Trade

In recent years, the academic community has further explored the pathways of digital economic development. Shu Meng et al. suggested that the digital economy can promote Arab economic diversification and transformation by fostering female entrepreneurship and employment. The mechanism by which the digital economy affects international trade is intricate, with existing literature primarily focusing on the study of mechanisms such as industrial structure upgrading and technological innovation. Chunying Cui, through empirical research on 283 cities in China, demonstrated that the development of the digital economy can promote market-oriented development, which plays a significant role in the domestic non-trade sector. Huang Wan, through studying the mechanism of the digital economy's impact on export trade, concluded that the development of the digital economy can positively affect export trade by promoting industrial structure upgrading and technological innovation. Urban development is closely intertwined with the development of foreign trade. Lu Yuxiu found that the digital economy is a new driving force for urban economic development. It not only promotes local urban economic development but also empowers high-quality economic development through the transmission mechanisms of technological innovation and industrial structure optimization. Wang Lixin further explored the heterogeneity of digital trade

development levels among the eight major urban clusters and finds that while the level of digital trade in these clusters continues to rise, there is evident regional heterogeneity among them.

### **2.3. Regional Heterogeneity of the Impact of the Digital Economy on International Trade**

Simultaneously, many scholars have recognized the regional heterogeneity in the impact of digital economic development on import and export trade. Fan Xin, synthesizing data from 115 countries and regions, found that the development of the digital economy in importing countries significantly improves China's export trade efficiency, with this effect being more pronounced for China's exports to middle- to low-income countries. Ma Zhaoliang et al., in their study of 31 provinces in China, found a high correlation between the improvement of China's export trade level and the development of the digital economy. They also suggest that there may be a threshold for digital economy service export trade, with a more pronounced promoting effect on the eastern and central regions of China. Zhao Wei, in a study of 284 prefecture-level cities in China, found that the digital economy significantly promotes the high-quality development of urban foreign trade, with its promoting effect being more pronounced in cities in the central and western regions, peripheral cities, cities with high levels of internet development, and cities designated as "big data comprehensive experimental zones". Wang Yu found in their research that the level of the digital economy has a positive effect on the scale and quality of exports of cities in the Yangtze River Delta region, with the intensity of the effect being greater for non-core cities than core cities.

### **2.4. Review**

In summary, the academic community currently has certain conclusions regarding the impact of the digital economy on international trade, which have some reference significance for this study. The marginal contributions and innovations of this paper mainly lie in the following three aspects. First, existing literature often focuses on analyzing the threshold effects of digital economic development on import and export trade from the perspective of industrial structure level. This paper provides a new perspective for exploring the threshold effects of digital economic development on import and export trade by empirically analyzing indicators such as technological innovation and urbanization level, providing new empirical evidence for the threshold effects of digital economic development on import and export trade. At the same time, exploring the mediating effects of technological innovation level and conducting in-depth exploration of the mechanisms by which digital economic development affects international trade from multiple dimensions enhance the overall research structure of the mechanisms by which the digital economy affects import and export trade. Second, previous literature mainly focused on regional heterogeneity analysis at the provincial level. This paper focuses on the regional heterogeneity of the multiple impact mechanisms of digital economic development on import and export trade among the three major economic city clusters in China (the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin-Hebei region), deeply analyzing the heterogeneity among these high-quality development regions and providing targeted suggestions for these regions to further improve their trade development levels, while also providing reference for the import and export trade development of other provinces and cities. Third, this paper uses the K-means clustering algorithm, combined with big data analysis, to further explore the regional heterogeneity of the impact of digital economic development on import and export trade when technological innovation level serves as a mediating variable.

## **3. Theoretical Analysis and Research Hypotheses**

The development of the digital economy has accelerated the dissemination of knowledge and technology, thereby driving the development of import and export trade. Along with the improvement of technological innovation level, the application of digital technology has become more widespread and profound. Firstly, the development of the digital economy has spurred breakthroughs in communication technology, enabling businesses to achieve high efficiency in production, marketing,

and other aspects. The use of digital payment, smart logistics, and other technologies has also streamlined the transaction process, enabling faster responses to market changes in import and export trade, improving trade efficiency, and reducing production costs and transaction costs. Secondly, the development of the digital economy under the conditions of technological innovation has fostered a series of emerging business models. Technologies such as cloud computing, big data, and artificial intelligence have provided a better platform for import and export trade. Meanwhile, businesses find it easier to enter the global market, thereby promoting import and export trade. The platformization, networking, and globalization features of the digital economy increase the development space for enterprises, facilitating quicker responses to market demands, optimizing resource allocation, enhancing market competitiveness, and consequently increasing trade opportunities for businesses. Based on this, this paper proposes the following hypotheses:

H1: The digital economy can drive import and export trade by promoting technological innovation.

H2: The higher the level of technological innovation, the more positively the development of the digital economy affects import and export trade.

With the advancement of urbanization, the impact of the development of the digital economy on import and export trade is reflected in several aspects. Firstly, urbanization helps promote industrial structure upgrading, accelerating the process of industrialization and modernization. This provides a better industrial foundation and market environment for the development of the digital economy, thereby promoting innovation and application of digital technology and driving the development of import and export trade. Secondly, as urbanization progresses, residents' income levels rise, leading to changes in consumption demand and structure. The demand for digital products and services increases, providing a broader market outlook for the development of the digital economy. The development of the digital economy, in turn, promotes consumption upgrading and expands domestic demand, forming a virtuous cycle. Thirdly, urbanization can drive regional economic integration and globalization processes, providing a broader international cooperation platform for the development of the digital economy. With the advancement of urbanization, economic ties between regions become closer, leading to a significant increase in international trade and investment activities.

Per capita GDP is an important indicator for measuring the level of economic development in a country or region. A higher value indicates more developed economic activities in that area. On the other hand, a higher degree of fiscal decentralization indicates greater freedom in fiscal allocation, with local governments possessing more resource allocation capabilities. Therefore, the social development status of a region is comprehensively evaluated based on three indicators: urbanization rate, per capita GDP, and degree of fiscal decentralization. Regions with relatively lower development quality may not be able to adapt to the changes brought by the development of the digital economy. Conversely, regions with relatively higher development quality can better adapt to the scientific and technological updates under the wave of the digital economy by leveraging their existing advantages, thus making significant contributions to the promotion of import and export trade through the development of the digital economy. Based on this, the following hypotheses are proposed:

H3: The higher the urbanization rate, the more positively the level of digital economic development affects import and export trade.

H4: In regions with relatively higher development quality, the level of technological innovation is more likely to produce a mediating effect in the impact of digital economic development on import and export trade

## 4. Research Design

### 4.1. Data Sources

Considering the accessibility and accuracy of the data, this study selects panel data from 42 cities in the three major city clusters in China: the Yangtze River Delta (Shanghai, Nanjing, Wuxi, Suzhou, Changzhou, Zhenjiang, Yangzhou, Nantong, Taizhou, Hangzhou, Ningbo, Jiaxing, Shaoxing, Zhoushan, Huzhou, Taizhou, Wuhu, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou, Xuancheng),

the Pearl River Delta (Guangzhou, Shenzhen, Jiangmen, Dongguan, Zhongshan, Zhuhai, Foshan, Zhaoqing, Huizhou), and the Beijing-Tianjin-Hebei region (Beijing, Tianjin, Shijiazhuang, Baoding, Tangshan, Qinhuangdao, Cangzhou, Zhangjiakou, Chengde, Langfang) from 2011 to 2021 for empirical analysis. The data sources include China City Statistical Yearbook, China Statistical Yearbook, relevant data reports released by the National Bureau of Statistics, Peking University's Inclusive Finance Index, China Regional Innovation and Entrepreneurship Index, EPS database, Guotai'an database, and Zhongjing Network statistical database, among others.

## 4.2. Variable Description

**Core Explanatory Variable:** Digital Economic Development Level (Dig)

Building on the methodology proposed by Liu Jun et al., which measures Internet development as the core metric and constructs the indicator system of the digital economy, combined with the availability of relevant data at the city level, the development level of the digital economy is comprehensively calculated from the dimensions of Internet development and digital financial inclusion. The measurement of Internet Development refers to the method used by Huang Qunhui et al., using indicators such as Internet penetration rate, relevant employment situation, relevant output situation, and mobile phone penetration rate. The measurement of Digital Financial Inclusion adopts the China Digital Inclusive Finance Index jointly compiled by Peking University's Digital Finance Research Center and Ant Group. Principal component analysis is employed to comprehensively calculate the digital economic development index based on various sub-indicators.

**Dependent Variable:** Import and Export Trade Level (Tra)

In this study, the level of import and export trade is measured using the total import and export trade volume of each city. A higher value indicates a higher level of import and export trade. The trade volume is converted from US dollars to Chinese yuan using the exchange rates for each year.

**Control Variables:**

(1) Foreign Direct Investment Scale ( $FDI_{it}$ ): It is measured by the actual amount of foreign investment used in the current year.

(2) Trade Openness Level ( $Inter_{it}$ ): Adopting the method proposed by Ma Zhaoliang, trade dependency is used to measure the level of trade openness.

(3) Economic Development Level ( $\ln PGDP_{it}$ ): Following the approach of Walsh et al., the logarithm of per capita GDP is used to measure the economic development level.

(4) Human Resources Situation ( $HR_{it}$ ): Referring to the method used by Zhan Xinyu, the proportion of students enrolled in ordinary institutions of higher education to the total population of the region is used to reflect the human resources situation.

(5) Degree of Fiscal Decentralization ( $Fiana_{it}$ ): Following the method proposed by Zhao Wei, the ratio of general public budget revenue to general public budget expenditure is used to represent fiscal decentralization.

(6) Government Intervention Level ( $Gov_{it}$ ): It is measured by the ratio of urban fiscal expenditure to urban GDP.

(7) Industrial Structure Level ( $Ind_{it}$ ): Following the practice of most literature, the ratio of value added of the tertiary industry to regional GDP is used to measure the industrial structure level.

(8) Volume of Road Transport ( $volume_{it}$ ): It is measured by the volume of road freight transport.

**Mediating Variable:** Technological Innovation Level (Tech)

In this study, it is believed that the digital economy provides diverse paths for innovation, and the continuous update and iteration of technology will inevitably promote import and export trade. Following the method proposed by Wang Xiaowen et al., the number of green patents authorized is selected to measure the level of technological innovation.

**Threshold Variables:** Technological Innovation Level (Tech) and Urbanization Level (Urban)

The measurement method for technological innovation level is the same as mentioned above. The urbanization level is measured by the proportion of urban resident population to the total population.

After simple processing of the above variables, descriptive statistical results are obtained as shown in Table 1. Data processing and estimation were conducted using Stata 17.0.

**Table 1.** descriptive statistical results for the main variables(N=462)

Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
Tra	48.943	84.426	0.066	406.104
DIG	0.861	0.850	-0.763	3.839
Inter	0.533	0.560	0.004	3.108
FDI	1.850	2.685	0.025	20.475
Finan	0.690	0.207	0.259	1.107
HR	305.779	277.524	20.465	1395.819
lnPGDP	6.659	0.510	5.376	7.618
Gov	0.311	0.229	0.059	1.153
Ind	0.469	0.108	0.000	0.839
volume	166.005	132.379	22.650	883.520
Tech	14.673	24.555	0.130	182.380
Urban	0.673	0.158	0.276	1.000

### 4.3. Model Construction

To examine the impact of the level of digital economic development (*Dig*) on import and export trade (*Tra*), this study first constructs the following baseline model:

$$Tra_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_2 X_{it} + \varepsilon_{it} \tag{1}$$

Among them, *i* represents cities, *t* (*t* = 2011, ..., 2021) represents time, *X*<sub>it</sub> represents a series of control variables, and  $\varepsilon_{it}$  represents random disturbances. Equation (1) is used to test the direct effect of the level of digital economic development on import and export trade. To examine whether the level of digital economic development indirectly affects import and export trade through its impact on technological innovation, this study follows the testing steps proposed by Wen Zhonglin et al. as follows: Based on Equation (1), construct a linear regression equation of the level of digital economic development (*Dig*) on the mediating variable of technological innovation level (*Tech*), as well as a linear regression equation of the level of digital economic development (*Dig*) and the level of technological innovation (*Tech*) on import and export trade *Tra*. The significance levels of  $\alpha_1$ ,  $\gamma_1$  and  $\gamma_2$  are used to determine whether there is a mediating effect. The model is as follows:

$$Tech_{it} = \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 X_{it} + \varepsilon_{it} \tag{2}$$

$$Tra_{it} = \gamma_0 + \gamma_1 Dig_{it} + \gamma_2 Tech_{it} + \gamma_3 X_{it} + \varepsilon_{it} \tag{3}$$

Considering that the level of technological innovation and urbanization may have a nonlinear effect on the promotion of foreign trade by the digital economy, a threshold model proposed by Hansen is adopted to test whether there is a threshold effect between the level of digital economic development (*Dig*) and import and export trade (*Tra*), to determine if there is a significant nonlinear relationship between the two, the following threshold regression model is constructed:

$$Tra_{it} = \theta_0 + \theta_1 Dig_{it} \times I \cdot (q_{it} \leq \gamma) + \theta_2 Dig_{it} \times I \cdot (q_{it} > \gamma) + \theta_3 X_{it} + \varepsilon_{it} \tag{4}$$

Among them,  $q_{it}$  is the threshold variable, including the level of technological innovation and urbanization;  $\gamma$  is the threshold value to be estimated; *I*( $\cdot$ ) is the indicator function, which equals 1 when  $q_{it} \leq \gamma$ , otherwise 0.  $\theta_1$  represents the coefficient of the impact of economic development on import and export trade when the level of technological innovation or urbanization is below, and  $\theta_2$

represents the coefficient of impact when the level of technological innovation or urbanization is above  $\gamma$ .

## 5. Empirical Testing and Analysis

### 5.1. Analysis of the Mediating Effect of Technological Innovation

Observing the overall test results of the three major city clusters, it can be noted that in Column (1), for every 1% increase in the level of digital economic development, there is an increase of 7.249 units in import and export trade. The regression result is positive at the 5% confidence level, indicating that the digital economic development significantly enhances the overall import and export trade level of the three major city clusters, thus validating Equation (1). In Column (2), the regression coefficient of the level of digital economic development on the level of technological innovation is 6.936. This implies that for every 1% increase in the level of digital economic development, there is a 6.936% increase in technological innovation level. The regression result is positive at the 5% confidence level, indicating a significant promoting effect of digital economic development on technological innovation level. Equation (2) is validated. In Column (3), after considering the technological innovation level as a mediating variable, the regression coefficient of the level of digital economic development on import and export trade is 3.415, which is lower than the regression coefficient of 7.249 in Column (1). Additionally, the promoting effect of the mediating variable, technological innovation level, on import and export trade is significantly positive at the 1% level. In conclusion, the promotion effect of digital economic development on import and export trade can be achieved through promoting the level of technological innovation, validating Equation (3) and confirming H1.

Based on the uneven regional development constraints on import and export trade, in order to achieve long-term stable development, further exploration was conducted on the regional heterogeneity of the three major urban clusters: the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin-Hebei region. Analysis of the Beijing-Tianjin-Hebei urban cluster in column (1) revealed that the development of the digital economy does not have a significant impact on import and export trade. This suggests that the main influencing factors for import and export trade in this region are not the level of digital economic development, but possibly trade policies, resource abundance, exchange rate levels, and other factors. Analysis of the Yangtze River Delta and Pearl River Delta urban clusters in columns (1) and (2) respectively showed that the development of the digital economy has a significant promoting effect on both import and export trade and technological innovation levels. The regression results for the development of the digital economy in the Yangtze River Delta and Pearl River Delta urban clusters regarding import and export trade and technological innovation levels were positive at the 1% confidence level. However, the regression coefficients for the development of the digital economy in the Pearl River Delta urban cluster were significantly higher than those in the Yangtze River Delta urban cluster, indicating that the import and export trade and technological innovation levels in the Pearl River Delta urban cluster are more easily influenced by the level of digital economic development. In the comparison analysis of columns (3) for the Yangtze River Delta and Pearl River Delta urban clusters, it was found that in the Yangtze River Delta urban cluster, when technological innovation levels are used as intermediary variables, the development of the digital economy has a significant promoting effect on import and export trade. However, in the Pearl River Delta urban cluster, when technological innovation levels are used as intermediary variables, the development of the digital economy does not have a significant promoting effect on import and export trade. This indicates that technological innovation levels can only produce significant intermediary effects in the Yangtze River Delta urban cluster, while they do not produce intermediary effects in the Pearl River Delta urban cluster. This regional heterogeneity suggests that in the Pearl River Delta urban cluster, the promotion effect of the digital economy on import and export trade is mainly not achieved through promoting technological innovation but rather through influencing factors such as human capital levels and volume of highway transportation. At the same

time, this also indicates that the Yangtze River Delta urban cluster is better able to adapt to the iterative updates of science and technology under the wave of the digital economy, leveraging its existing advantages.

**Table 2.** Test of the Mediating Effect of Technological Innovation

Variable	Total		the Beijing-Tianjin-Hebei region			the Yangtze River Delta			the Pearl River Delta				
	(1) Tra	(2) Tech	(3) Tra	(1) Tra	(2) Tech	(3) Tra	(1) Tra	(2) Tech	(3) Tra	(1) Tra	(2) Tech	(3) Tra	
DIG	7.249** (3.002)	6.936** (2.945)	3.415* (2.057)	8.467 (5.476)	0.726 (5.779)	7.695 (4.739)	5.671*** (1.930)	5.295*** (1.882)	4.384* (2.367)	46.844*** (16.037)	15.320*** (4.574)	45.807*** (11.416)	
Inter	17.920*** (6.444)	-7.718** (3.908)	25.922*** (8.430)	179.131*** (21.861)	16.595 (19.685)	161.487*** (8.763)	22.447*** (6.386)	-13.014*** (4.602)	35.992*** (11.510)	55.372*** (9.937)	-8.034 (7.514)	55.916*** (8.278)	
FDI	1.538 (0.943)	3.075 (2.076)	1.167* (0.642)	5.335** (2.631)	3.062 (2.442)	2.080*** (0.438)	5.448* (2.982)	2.201* (1.247)	4.869** (2.481)	11.494 (7.844)	9.700* (5.882)	10.837 (9.230)	
Finan	17.745 (11.126)	5.168 (8.868)	26.748*** (10.312)	-51.792 (52.398)	-33.854 (26.283)	-15.795 (38.816)	11.293 (9.384)	6.770 (6.836)	14.956 (10.104)	40.210 (51.926)	-5.817 (26.731)	40.603 (54.110)	
HR	-0.002 (0.012)	0.002 (0.006)	-0.005 (0.013)	-0.086** (0.042)	-0.031 (0.025)	-0.054 (0.036)	0.010 (0.013)	0.016*** (0.006)	0.005 (0.008)	-0.112*** (0.027)	0.001 (0.009)	-0.112*** (0.027)	
lnPGDP	7.569 (4.697)	11.382** (5.497)	4.927 (4.178)	32.754* (17.795)	25.371 (14.496)	5.778 (7.906)	0.406 (6.651)	17.103 (10.668)	-2.369 (8.010)	69.140** (32.932)	-8.416 (13.773)	69.710** (31.715)	
Gov	-2.997 (6.171)	3.521 (6.716)	-0.526 (4.761)	-33.506 (26.697)	-16.748* (16.320)	-15.698 (13.555)	-3.928 (9.168)	14.095 (9.176)	-5.420 (9.112)	-355.380*** (95.679)	-32.859 (35.649)	-353.156*** (95.494)	
Ind	12.752* (6.822)	25.702 (31.609)	13.669 (9.945)	162.122* (89.087)	161.545** (69.452)	-9.643 (29.710)	19.213*** (6.276)	-8.506 (13.196)	21.467** (8.968)	253.307 (160.646)	-19.601 (51.244)	254.633 (158.081)	
Urban	-20.367 (14.486)	3.521 (13.549)	-7.619 (13.172)	-98.400 (69.495)	-79.997* (47.370)	-13.343 (31.106)	-4.105 (24.624)	-14.678 (48.444)	-2.227 (29.115)	-93.055 (83.599)	49.667 (36.878)	-96.417 (79.477)	
volume	0.048** (0.023)	0.018 (0.022)	0.034* (0.020)	-0.060 (0.044)	0.003 (0.035)	-0.063*** (0.023)	0.103*** (0.034)	0.077*** (0.027)	0.070* (0.040)	-0.098** (0.041)	-0.047*** (0.016)	-0.095*** (0.029)	
Tech			0.398*** (0.072)			1.063*** (0.078)			0.351*** (0.080)			0.068 (0.387)	
Constant	-31.034 (23.980)	-91.802*** (34.747)	-32.247 (22.963)	-174.457* (102.927)	-155.135* (88.083)	-9.508 (44.703)	-13.273 (38.839)	-114.186** (52.523)	-2.019 (41.474)	-489.235** (190.615)	33.391 (87.108)	-491.495*** (186.347)	
N	462		110			253			99				
R <sup>2</sup>	0.673	0.576	0.768	0.944	0.787	0.981	0.838	0.680	0.864	0.921	0.762	0.921	

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## 5.2. Threshold Effect Analysis

### 5.2.1 Analysis of the Threshold Effect of Technological Innovation Level

To examine whether there exists a nonlinear effect of the digital economy development level on import and export trade with technological innovation level as the threshold variable, this study further employs a threshold effect model for analysis. Table 3 shows that there is a single threshold effect of the digital economy development on the overall import and export trade of the three major urban clusters with technological innovation level as the threshold variable, with a threshold value of 87.480. Hence, H2 is supported.

Based on the preceding analysis, further exploration of the regional heterogeneity among the three major urban clusters was conducted. In the Beijing-Tianjin-Hebei and Yangtze River Delta urban clusters, there is a single threshold effect of the digital economy development on import and export trade with technological innovation level as the threshold variable, with threshold values of 22.210 and 68.240, respectively. This regional heterogeneity may stem from the advanced industrial structure in the Yangtze River Delta urban cluster, particularly in high-tech industries, leading to higher requirements for technological innovation in this region and thus increasing the threshold value with technological innovation level as the threshold variable. In the Pearl River Delta urban cluster, the digital economy development does not exhibit a threshold effect with technological innovation level as the threshold variable on import and export trade. This may be attributed to the relatively developed industrial sector in this region, primarily dominated by light industry, and its lower reliance on technological innovation, with more emphasis placed on measures such as attracting foreign investment.

**Table 3.** Test of the Threshold Effect of Technological Innovation Level

	Threshold Nature	F Value	P Value	BS Iterations	Critical Value			Threshold Estimate
					1%	5%	10%	
Overall	Single Threshold	109.700***	0.000		53.908	27.111	18.693	87.480
Beijing-Tianjin-Hebei	Single Threshold	168.990***	0.000	100	25.494	20.872	16.393	22.210
Yangtze River Delta	Single Threshold	122.460***	0.000		33.548	30.675	24.319	68.240

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The threshold regression test results are shown in Table 4. The overall results indicate that when the level of technological innovation is below 87.480, the level of digital economic development significantly promotes foreign trade, with a coefficient of 3.085. However, when the level of technological innovation exceeds 87.480, the impact of digital economic development on foreign trade becomes even more significant, with a coefficient of 13.528. This suggests that after the threshold value of technological development is reached, the impact of digital economic development on foreign trade intensifies, indicating a non-linear effect of digital economic development on foreign trade.

Based on the previous analysis, further exploration of the regional heterogeneity of the Beijing-Tianjin-Hebei regions and Yangtze River Delta city clusters reveals interesting findings. By examining the estimation results of both regions, it is observed that when the level of technological innovation is below 22.210, the coefficient of digital economic development is negative. However, when the level of technological innovation exceeds 22.210, the coefficient of digital economic development becomes positive. This indicates that as the level of technological innovation increases, the impact of digital economic development on foreign trade in the region first exhibits a restraining effect before transitioning to a promoting effect, although the restraining effect is not significant. This result may be attributed to the existence of technological bottlenecks in the early stages of technological development. As scientific and technological capabilities further improve, the advantages of the digital economy begin to manifest, thereby introducing new growth points for foreign trade. For the Yangtze River Delta city cluster, the estimation results indicate that when technological innovation surpasses the threshold value of 68.240, the impact of digital economic development on foreign trade strengthens. This outcome suggests that when technological innovation levels are low, traditional trading methods may still dominate, making it difficult for the digital economy to play a significant role in promoting foreign trade. However, once the threshold value of technological innovation is reached, the emergence of new trade methods combined with the advantages of the digital economy further promotes the development of foreign trade.

**Table 4.** Estimation Results of the Technology Innovation Threshold Model

Variable	Tra					
	Overall		the Beijing-Tianjin-Hebei regions		Yangtze River Delta city clusters	
	Coefficient	t	coefficient	t	coefficient	t
Inter	16.769***	9.030	121.977***	19.570	20.323***	8.710
FDI	0.107	0.320	1.443***	4.650	1.349**	2.400
Finan	2.874	0.430	-6.416	-0.400	4.171	0.710
HR	-0.003	-0.350	0.031**	2.270	0.015*	1.850
lnPGDP	7.600***	2.870	9.176**	2.240	3.980	1.490
Gov	3.396	0.500	0.002	0.000	2.731	0.490
Ind	26.510***	3.390	32.403	1.660	40.714***	6.890
Urban	-29.142***	-3.020	-22.059	-1.550	-24.790*	-1.940
Volume	0.038***	4.650	-0.019	-1.360	0.071***	8.940
DIG(Tech≤ γ)	3.085**	2.120	-3.053	-1.090	2.134*	1.760
DIG(Tech> γ)	13.528***	8.380	93.023***	12.600	13.595***	8.800
_cons	-15.499	-0.880	-64.545**	-2.240	-17.071	-1.120

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

### 5.2.2 Urbanization Threshold Effect Analysis

To examine whether there is a nonlinear effect of digital economic development on import and export trade with urbanization level as the threshold variable, this study further analyzes using a threshold effect model. Table 5 shows that there is a single threshold effect of digital economic development on import and export trade for the overall three major city clusters, with the urbanization level as the threshold variable, and the threshold value is 0.875. Hence, H3 is established.

Based on the previous analysis, further exploration of the regional heterogeneity of the three major city clusters reveals that in the Beijing-Tianjin-Hebei and Pearl River Delta city clusters, there is a single threshold effect of digital economic development on import and export trade with urbanization level as the threshold variable, with threshold values of 0.849 and 0.865 respectively. However, in the Yangtze River Delta city cluster, there is no threshold effect of urbanization level on the impact of digital economic development on import and export trade. This may be due to the relatively mature development level and high urbanization degree in the region, where urbanization promotion is not the primary factor driving the promotion of import and export trade by digital economic development. In contrast, other factors such as technological innovation, industrial structure, and policy environment may be more important.

**Table 5** Test of Urbanization Threshold Effect

	Threshold Nature	F	P	BS Iterations	Critical Value			Threshold Estimate
					1%	5%	10%	
Overall	Single Threshold	43.680**	0.010		42.473	31.196	26.622	0.875
Beijing-Tianjin-Hebei regions	Single Threshold	48.370***	0.000	100	31.485	16.705	14.835	0.849
Yangtze River Delta city cluster	Single Threshold	26.690*	0.050		40.359	26.584	20.221	0.865

Note: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

The threshold regression test results are shown in Table 6. The overall results indicate that when the urbanization level is below 0.875, the coefficient of digital economic development is -0.560, and the result is not statistically significant, suggesting that the inhibitory effect of digital economic development on import and export trade is not significant. However, when the urbanization level is above 0.875, the coefficient of digital economic development is 13.898, and it is significant at the 1% level, indicating that digital economic development significantly promotes import and export trade. Thus, it can be inferred that digital economic development only promotes import and export trade when the urbanization level reaches a certain threshold, demonstrating the nonlinear impact of digital economic development on import and export trade.

Based on the previous analysis, further exploration into the regional heterogeneity of the Beijing-Tianjin-Hebei regions and the Pearl River Delta urban agglomerations reveals interesting findings. Upon observing the estimation results of both, it is noted that when the urbanization level has not crossed the threshold value, the coefficients of digital economic development are negative. However, once the urbanization level surpasses the threshold, the coefficients of digital economic development become positive, indicating an initial inhibitory effect followed by a promoting effect on import and export trade. Moreover, the inhibitory effect in the Pearl River Delta urban agglomeration passes the significance test at the 5% level, while the promoting effect in the Beijing-Tianjin-Hebei regions and the Pearl River Delta urban agglomerations passes the significance test at the 1% level. This outcome may be attributed to the lower urbanization level, which imposes constraints on various aspects such as resources, infrastructure, and institutional environment, hindering the rapid development of the digital economy's push for import and export trade. This constraint is more pronounced in the Pearl River Delta region. As the urbanization level further increases, the improvement in urban infrastructure and optimization of institutional environment gradually enhances market openness and trade facilitation, leading to the gradual manifestation of the promoting effect of digital economic development on import and export trade, which is significant in both the Beijing-Tianjin-Hebei regions and Pearl River Delta urban agglomerations.

**Table 6.** Estimation Results of the Urbanization Threshold Model

Variable	Tra					
	Overall		Beijing-Tianjin-Hebei regions		Pearl River Delta urban agglomerations	
	Coefficient	t	Coefficient	t	Coefficient	t
Tech	0.324***	11.410	0.298***	3.820	0.394***	10.250
Inter	24.384***	12.690	134.829***	20.940	16.150***	7.850
FDI	0.252	0.820	0.686**	2.310	-0.791	-0.900
Finan	4.221	0.660	1.055	0.080	22.415***	2.770
HR	-0.010	-1.440	0.035***	3.020	-0.024***	-2.820
lnPGDP	3.890*	1.810	5.199	1.660	13.260**	2.430
Gov	-0.201	-0.030	3.445	0.450	43.512	1.190
Ind	10.391	1.530	10.303	0.720	-5.502	-0.270
volume	0.029***	3.760	-0.031**	-2.600	0.013	1.330
DIG(Urban ≤ γ)	-0.560	-0.400	-4.647	-1.960	-4.936**	-2.130
DIG(Urban > γ)	13.898***	5.870	84.446***	6.360	6.815***	3.130
_cons	-7.272	-0.460	-49.322**	-2.120	-48.038	-1.300

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## 6. Empirical Testing and Analysis

Cluster analysis, also known as clustering, is the process of dividing a collection of physical or abstract objects into different classes or clusters according to a specific criterion. K-means clustering is an unsupervised learning method, which means that it assigns data points to multiple clusters without predefined target variables. It searches for the underlying structure of data objects in a given dataset, aiming to make objects within the same cluster as similar as possible and objects from different clusters as dissimilar as possible. In essence, it aims to identify similarities and patterns hidden within the data.

This paper delves into the role of the variable of technological innovation level in the impact of digital economic development on import and export trade, with a focus on a significant tool in big data analysis—the K-means algorithm—calculating its behavioral patterns when attributed to different groups. Due to the limited sample size, the paper divides the three indicators of fiscal decentralization, economic development level, and urbanization level of 462 samples into two different clusters for K-means clustering. Further clustering results for corresponding parameters of each grade are obtained using Stata 17.0, as shown in Table 6.1. By comparing the statistical results of samples in different clusters regarding fiscal decentralization, economic development level, and urbanization degree, it is evident that the mean values of each indicator in Cluster 1 are higher than those in Cluster 2. This indicates a higher level of development in Cluster 1 and a lower level of development in Cluster 2.

**Table 7.** Descriptive Statistics of Variables in K-Means Clustering

Variable	Sample Size	K=1				K=2				
		Mean	Variance	Minimum	Maximum	Sample Size	Mean	Variance	Minimum	Maximum
Finan	285	0.795	0.158	0.435	1.107	177	0.520	0.159	0.259	0.989
lnPGDP	285	6.995	0.267	6.423	7.618	177	6.117	0.297	5.376	6.627
Urban	285	0.763	0.115	0.523	1.000	177	0.528	0.100	0.276	0.886

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Based on the statistical results of the K-means clustering algorithm, further regression results are presented in Table 8. Observing the results for Cluster 1, column (1) indicates a significant positive impact of digital economic development on import and export trade at a 5% confidence level. Column (2) shows a significant positive impact of digital economic development on technological innovation level at a 1% confidence level. Column (3) demonstrates a significant positive impact of technological innovation level as a variable in driving the impact of digital economic development on import and export trade, at a 1% confidence level. This indicates that technological innovation level can generate a mediating effect in Cluster 1. Observing the results for Cluster 2, column (2) indicates that digital

economic development has no significant impact on technological innovation level, suggesting that technological innovation level does not generate a mediating effect in Cluster 2.

In summary, in regions with relatively high levels of development, technological innovation level mediates the impact of digital economic development on import and export trade. In regions with relatively low levels of development, technological innovation level does not mediate the impact of digital economic development on import and export trade. Thus, H4 is supported.

**Table 8.** Regression Results Based on K-Means Clustering Algorithm

Variable	K=1			K=2		
	(1) Tra	(2) Tech	(3) Tra	(1) Tra	(2) Tech	(3) Tra
DIG	12.366** (4.927)	11.779*** (2.426)	7.000* (4.252)	0.655*** (0.192)	0.578 (0.486)	0.252 (0.176)
FDI	2.153* (1.116)	3.350** (1.527)	2.083** (0.955)	0.630 (0.447)	1.408*** (0.539)	0.271 (0.287)
HR	-0.005 (0.018)	-0.001 (0.008)	-0.014 (0.020)	0.002 (0.003)	0.003 (0.003)	-0.001 (0.002)
Gov	-37.916 (30.523)	-25.417** (10.425)	-33.115 (24.878)	-1.504** (0.589)	0.178 (0.935)	-0.989** (0.490)
Ind	31.154* (17.044)	84.881* (51.228)	31.820* (18.501)	3.416* (2.007)	17.733*** (4.602)	-1.582 (1.496)
Inter	23.723*** (7.813)	-6.678** (3.304)	35.666*** (11.938)	10.362** (5.021)	0.590 (0.452)	8.347** (3.421)
volume	0.068* (0.039)	-0.013 (0.026)	0.055* (0.031)	0.007*** (0.002)	0.011*** (0.004)	0.004*** (0.002)
Tech			0.396*** (0.077)			0.283*** (0.079)
Constant	13.313 (17.073)	-28.600 (22.015)	7.922 (15.547)	6.618 (4.321)	-8.118*** (2.724)	9.877 (4.563)
N		285			177	
R <sup>2</sup>	0.708	0.585	0.828	0.828	0.597	0.834

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## 7. Robustness Analysis

In the preceding sections, the mediating effect of technological innovation level on the impact of digital economic development on import and export trade was examined using stepwise regression coefficient testing. To further test the robustness of the research results, the Sobel test was employed to examine the mediating effect of technological innovation level. The test results, as shown in Table 9, align with those presented earlier, indicating the robustness of the research findings.

**Table 9.** Test Results by Sobel

	Coefficient	Standard Error	Z	P> Z
Overall	3.607**	1.410	2.558	0.011
Beijing-Tianjin-Hebei regions	0.772	2.952	0.262	0.794
the Yangtze River Delta city cluster	4.296**	2.049	2.097	0.036
the Pearl River Delta city cluster	1.037	3.180	0.326	0.744

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

To verify the robustness of the threshold effect test results, this study employs a variable substitution method for testing. Urbanization level is measured by the ratio of non-agricultural population to total registered population, while technological innovation level is measured by the number of higher education institutions in the innovation environment index. Regression results demonstrate consistent significance and threshold quantities with the previous analysis, indicating the robustness of the research findings.

**Table 10.** Robustness Test Results of the Threshold Effects

Threshold Variable	Threshold Nature	F-Value	P-Value	BS Iterations	Critical Value			Threshold Estimate
					1%	5%	10%	
Technological Innovation Level	Single Threshold	41.370***	0.003	300	28.838	18.582	13.882	13.000
Urbanization Level	Single Threshold	36.030**	0.017		39.258	26.532	21.429	0.865

Note: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

## 8. Conclusion and Suggestions

This paper examines the impact and transmission mechanism of digital economic development on import and export trade from both macro and micro perspectives, as well as explores its regional heterogeneity. Due to the intricate nature of the mechanisms through which the digital economy affects international trade, the factors considered in this study may not be exhaustive and warrant further exploration.

The main conclusions are as follows:

(1) Digital economic development significantly promotes import and export trade. However, this impact is not significant in the Beijing-Tianjin-Hebei Urban Agglomeration; in the Yangtze River Delta Urban Agglomeration, digital economic development significantly affects trade, with technological innovation level mediating this effect; in the Pearl River Delta Urban Agglomeration, the impact is also significant, but technological innovation level does not mediate it. Governments and businesses should increase investment in technological innovation and establish a robust digital economy system to achieve long-term sustainable development of import and export trade.

(2) Technological innovation level exhibits a single-threshold positive promotion effect in the impact of digital economic development on import and export trade. In the Yangtze River Delta Urban Agglomeration, this promotion effect significantly increases after crossing the threshold; in the Beijing-Tianjin-Hebei Urban Agglomeration, it manifests as an initial inhibitory effect followed by a promotion effect, although the inhibitory effect is not significant; in the Pearl River Delta Urban Agglomeration, this threshold effect does not occur. China should continuously advance the development of science and technology, thereby enhancing market openness and facilitation of foreign trade, to achieve optimal resource allocation, maximize efficiency, and achieve overall balanced development.

(3) Urbanization level exhibits a single-threshold inhibitory effect followed by a promotion effect in the impact of digital economic development on import and export trade. This inhibitory effect is stronger in the Pearl River Delta Urban Agglomeration than in the Beijing-Tianjin-Hebei Urban Agglomeration; in the Yangtze River Delta Urban Agglomeration, this threshold effect does not occur. To avoid the inhibitory effect of urbanization level, governments should actively promote the urbanization process, implement policy support, infrastructure construction, deepen international cooperation, and provide important contributions to the promotion of digital economic development on import and export trade.

(4) In regions with higher development quality, technological innovation level is more likely to mediate the impact of digital economic development on import and export trade. Regions with high development quality should continue to leverage existing advantages to address the updates and iterations of science and technology under the wave of the digital economy. While fully leveraging the leading role of regions with high development levels, efforts should also be made to continuously improve infrastructure construction and optimize institutional environments in regions with lower development quality. This will achieve coordinated development between regions with high and low development quality, enhance China's advantageous position in the wave of digital economic development, and further promote high-quality economic and social development in China.

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