Mechanism and Empirical Research on the Influence of Digital Economy on Export Trade in the Yangtze River Delta Region

Binglin Zhu*

(1773092205@qq.com*)

School of Law, Economics and Trade, Chongqing University of Science and Technology, Chongqing 401331, China

Abstract. This paper utilizes panel data from all 41 prefecture-level cities in the Yangtze River Delta (YRD) region spanning 2011 to 2019 to conduct theoretical and empirical analyses. It explores how the digital economy influences export trade and examines the mediating effect of industrial agglomeration. Key findings include: (1) The digital economy significantly boosts product exports, a conclusion supported by robustness and endogeneity tests. (2) Export trade is more profoundly affected by the digital economy in the central YRD region than in the non-central area. This difference may be attributed to varying infrastructure levels and competition dynamics. (3) The digital economy's impact on export trade is mediated by industrial agglomeration, which plays a significant role. Furthermore, the paper proposes policy suggestions for governments and enterprises to promote the synergistic development of the digital economy and export trade in the Yangtze River Delta region.

Keywords: Digital Economy; Export Trade; Industrial Agglomeration.

1 Introduction

The digital economy, heralding a new era of global technological and industrial revolution, stands as a cornerstone of global economic development [1]. Emphasizing its strategic significance, the CPC, at the 20th National Congress, called for accelerating digital economy development, advocating for its deep integration with the real economy to foster internationally competitive digital industry clusters. This elevated attention from governments, enterprises, and individuals underscores its critical importance in contemporary discourse. In his congratulatory letter to the 2021 Wuzhen Summit of the World Internet Conference, Xi Jinping highlighted the transformative impact of digital technology across all facets of human society. He underscored the active integration of new concepts, business models, and forms into various aspects of economic, political, cultural, social, and ecological civilization-building through digital technologies. Indeed, these changes are reshaping our mode of production. As globalization accelerates, the nexus between the digital economy and international trade deepens, propelling the digital economy to emerge as a potent driver of economic growth [2]. According to the "China's Digital Economy Development White Paper (2021)," China's digital economy ranked second globally by the end of 2020, with a total size of $54 trillion and an impressive annual growth rate of 9.6%, surpassing the GDP growth rate by more than 3.2

MSEA 2024, May 24-26, Jinan, People's Republic of China

DOI 10.4108/eai.24-5-2024.2350064

times. This resilience and potential exhibited by China's digital economy, particularly amidst challenging times, foreshadows even greater strides and advancements in the future. Amid trade conflicts and the COVID-19 pandemic, China's export trade has maintained steady growth despite facing various challenges, including a slowdown in traditional trade growth, rising trade frictions, and the imperative to reshape the global industrial chain [1]. In 2021, China's export trade surged by 21.2 percentage points, securing its position as the global leader in total goods trade for five consecutive years. This begs the question: what fuels this rapid and stable trade growth? Is there a correlation between this growth and the development of the digital economy? If so, how does the digital economy influence export trade, and what mechanisms drive its impact? To address these inquiries, this paper delves into relevant literature.

Scholars worldwide have extensively explored the nexus between the digital economy and export trade, examining various aspects such as export trade costs [1], supply-side innovation and entrepreneurship [2], human capital [3], and innovation performance [4]. These studies offer valuable insights into the development of the digital economy and export trade in China. Research primarily focuses on the positive impact of the digital economy on export trade from two perspectives: trade in goods and trade in services. Regarding trade in goods, Yao Zhanqi [3] utilized eight years of microdata from multiple Chinese provinces and regions to construct a spatial lag model. The study empirically demonstrated a significant positive spatial correlation between the digital economy and the export competitiveness of the manufacturing industry. It revealed that the digital economy not only enhances the export competitiveness of the local region but also stimulates neighboring regions' export competitiveness. This enhancement is attributed to reduced trade costs and optimized resource allocation effects [5]. Moreover, the digital economy significantly promotes industrial structure upgrading in export trade, with a more pronounced positive effect observed in China's central region compared to other areas [6]. Additionally, Yao Zhanqi [7] empirically examined the positive impact of digital trade on export complexity and product quality, particularly significant for manufacturing and trade among emerging economies [8]. In terms of trade in services, although traditionally constrained by spatial limitations, it constitutes a relatively small proportion of total trade [9]. However, with the rapid advancement of the digital economy, leveraging information technology and the internet, these spatial constraints are gradually diminishing. Remote transactions in trade-in services are witnessing a significant surge. Tao Aiping [10] conducted empirical research, concluding that the digital economy substantially promotes the development of trade in services. Developed countries exhibit higher overall levels of digital trade in services with slower growth rates while developing countries show lower levels but higher growth rates, especially in imports [10-11]. Similar to trade in goods, the digital economy also plays a crucial role in optimizing the industrial structure of trade in services [11]. Its strong permeability and integration capabilities facilitate integration with the service trade industry [12], promoting resource allocation optimization, total factor productivity improvement, and overall structural enhancement of the service industry and trade-in services [10]. In terms of influence mechanisms, the Internet's application enhances export information search efficiency [5], it facilitates efficient information communication and matching, stimulating export trade motivation by reducing communication and learning costs [6]. Moreover, the digital economy impacts the education system, promoting human capital accumulation, and thereby enhancing export competitiveness [3]. Furthermore, the increasing popularity of digital technology deepens consumer digitization, leading to the formation of digital consumption habits. This expansion of the digital economy creates new demand for digital trade in services, driving export growth in service trade [10].

In exploring the impact of the digital economy on export trade, it is imperative to define and measure the level of digital economy development. While numerous scholars have attempted to gauge this level, there remains no universally accepted standard for measurement indicators and methods in both domestic and international research. Measurement methods in existing literature primarily fall into two categories: single indicator measurement and comprehensive indicator system measurement. Single indicator measurement tends to be applied to more specific and narrow objects. For instance, He Fan et al. [13], in their study on the economic efficiency of the real economy, selected the digital transformation index to focus on the specific role of the digital economy relevant to their study, thereby eliminating unnecessary digital economy indicators. Conversely, Zhang Xun [14], in their study on household division of labor and personal time allocation, opted for the digital financial inclusion index, emphasizing the consumer field. Similarly, Fan Xin [15], Chen Fuzhong [16], and others pursued similar approaches, focusing on narrower topics. On the other hand, comprehensive indicator system measurement is better suited for complex or broader research objects. For example, Bo Peiwen and Zhang Yun [17] established an indicator system comprising digital industry, innovation, users, and platforms, using principal component analysis to measure the digital economy level. Similarly, Zhao Tao [18], in studying the impact of the digital economy on high-quality development, utilized principal component analysis to construct a comprehensive digital economy level index. Given the complex relationship between export trade and the digital economy, we opt for a comprehensive indicator system measurement, drawing inspiration from Zhao Tao [18], Liu Jun [19], and others, to ensure accuracy and robustness in our empirical findings.

The existing literature lays a solid groundwork for assessing the digital economy and its impact on export trade from various angles, including its influence on export industrial structure, trade complexity, competitiveness, and product quality. However, several gaps remain for further exploration. Firstly, most studies focus on provincial panels rather than specific municipal panels, overlooking the nuances of city-level development and resulting in findings lacking relevance and specificity. Secondly, there is a lack of empirical research on how the digital economy affects export trade through industrial agglomeration, with existing literature primarily focusing on trade costs, human capital, and creation effects. Lastly, the absence of empirical studies focusing on specific regions makes it challenging to provide targeted policy recommendations for these areas. To address these gaps, this paper utilizes panel data from 41 cities in the Yangtze River Delta from 2011 to 2019 to investigate the effects and mechanisms of the digital economy on export trade. The key innovations and contributions of this paper include analyzing the digital economy's promotion effect on total export trade volume to provide insights into stabilizing export growth. Additionally, we introduce the ratio of the output value of secondary and tertiary industries to urban construction land as a measure of industrial concentration, empirically demonstrating its intermediary effect between the digital economy and export trade. Furthermore, we use the ratio of output value to land area as a measure of industrial agglomeration, providing empirical evidence of its mediating effect on the relationship between the digital economy and export trade, thereby elucidating the underlying mechanisms.

2 Theoretical Logic and Research Hypotheses

2.1 Analysis of The Direct Effects of The Digital Economy and Exports

The concept of the digital economy, initially synonymous with the Internet economy or the information economy, was first introduced by Tapscott in his monograph "The Age of the Digital Economy". However, as science, technology, and the economy have advanced, the contemporary understanding of the digital economy has evolved. Broadly speaking, it now encompasses digital information as a key resource, the Internet platform as the primary information carrier, digital technology innovation as the driving force, and new models and business forms as manifestations of economic activities. As a novel form of economic and social development following the agricultural and industrial economies, the digital economy serves as a new engine for economic growth. It represents a defining feature of our times, influencing the characteristics of economies and offering new opportunities across national borders without necessitating physical migration [20]. While existing literature largely examines the impact of the digital economy on export trade through the lenses of digital technology and cross-border e-commerce, there is still much to explore in this dynamic field.

On the one hand, digital technology plays a pivotal role in shaping export trade dynamics by expanding market reach and reducing transaction costs. Serving as the cornerstone of the digital economy, modern technologies centered around computers and the Internet facilitate its seamless functioning and advancement. Information technology, a key component of digital technology, significantly influences the export decisions of private enterprises. The network effect of information infrastructure, not only encourages export propensity but also contributes to scaling up exports by leveraging stable resource integration on software platforms. Studies by Li Dan [22] and others have underscored how digital technology inputs can lower trade costs, boost R&D investment intensity, and enhance innovation transformation capacity. This, in turn, fosters the growth of China's manufacturing industry by promoting domestic value-added exports and bolstering export volumes. Moreover, enterprise digital transformation significantly boosts the export trade volume of Chinese enterprises. The application of digital technology enhances export competitiveness by improving cost advantages [23]. Beyond the level of information technology, the completeness of digital infrastructure also serves as a critical measure. Comprehensive digital infrastructure not only boosts innovation and resource allocation efficiency but also drives the upgrading of export industries [24]. Thus, an advanced digital infrastructure contributes to the overall enhancement of export performance, thereby fostering the growth of export trade.

On the other hand, Cross-border e-commerce similarly exerts a direct impact on export trade dynamics. In essence, it refers to international trade conducted through online platforms, leveraging Internet technology and global logistics networks. Its significance in export trade lies in its capacity to substantially reduce fixed costs associated with international trade [25] and overcome spatial constraints inherent in traditional trade [26]. Research by Li Xiaoping et al [27] highlights how cross-border e-commerce significantly enhances the product conversion rate of Chinese industrial enterprises, thereby bolstering total factor productivity and elevating export product quality. This phenomenon fosters efficient resource allocation within enterprises. Furthermore, cross-border e-commerce plays a pivotal role in enhancing trade performance, driving down export product prices, and facilitating structural upgrades in imported products [28].

Numerous scholars have acknowledged the positive impact of the digital economy on export trade. While many studies have concentrated on digital technology or cross-border e-commerce to examine specific aspects of the digital economy's influence on export trade, they consistently conclude that the digital economy facilitates export trade. Building upon this existing research, this paper synthesizes these findings and proposes the following hypothesis at the holistic level of the digital economy:

Hypothesis 1: The digital economy facilitates export trade.

2.2 Analysis of The Institutional Effects of The Digital Economy on Exports

As per the preceding assertion, the digital economy fosters industrial agglomeration, subsequently advancing export trade. Consequently, this paper will conduct a mechanism analysis from two perspectives: the digital economy and industrial agglomeration, and industrial agglomeration and export trade.

2.2.1 Digital Economy and Industrial Clustering

Industrial agglomeration refers to the concentration of diverse industries in a specific geographic area, where these industries share interdependencies and collaborate both vertically and horizontally. The digital economy, combining information technology and resource integration, exhibits a multi-core agglomeration pattern centered around urban hubs [29]. This transformative force transcends spatial constraints, reshaping traditional industrial structures and fostering synergistic agglomeration [30]. By catalyzing changes in production factors and enhancing informatization, the digital economy drives industrial upgrades and facilitates collaborative clustering [31]. Additionally, digital finance further reinforces the clustering of high-tech industries, amplifies economies of scale, and facilitates knowledge exchange, ultimately enhancing regional innovation dynamics [32]. Thus, it is evident that the digital economy not only amplifies the scale of industrial agglomeration but also elevates its quality. In light of these observations, this paper proposes:

Hypothesis 2: The digital economy facilitates the augmentation of industrial agglomeration.

2.2.2 Industrial Agglomeration and Export Trade

Industrial agglomeration embodies external economies of scale, fostering shared infrastructure and optimized resource utilization among enterprises. By reducing transportation and warehousing costs for both upstream and downstream entities, industrial agglomeration amplifies product scale and diminishes costs, thereby enhancing export competitiveness. Notably, it elevates technical efficiency in export trade by bolstering regional human capital and research and development capabilities [33]. The resultant knowledge spillover and production factor sharing outweigh competitive pressures, fostering export economy complexity. Concurrently, industrial agglomeration drives urban industrial upgrades by attracting high-complexity industries and facilitating the exit of low-complexity ones [34]. Sun Churen's [35] mechanistic inquiry further underscores industrial agglomeration's role in elevating export product quality, with differential impacts across ownership structures and trade modalities. Particularly, digital technology-rich high-tech industrial clusters exhibit pronounced positive effects on export industry upgrading [36]. In light of these insights, this paper posits:

Hypothesis 3: The digital economy fosters export trade by enhancing industrial agglomeration, thus stimulating export growth.

3 Indicator Measurement and Data Sources

3.1 Core Explanatory Variables

3.1.1 Selection of Indicators

The core explanatory variable in this study is the level of digital economy development in each prefecture-level city, denoted as "*dig*." Following previous research, we adopt a comprehensive indicator system to measure this variable, drawing inspiration from the methodologies of Zhao Tao [18] and Liu Jun [19]. We utilize five indicators to gauge digital economy development across five dimensions: Internet penetration, related employment, industry output, cell phone penetration, and digital finance advancement. Specifically, these indicators correspond to the following metrics: the number of broadband Internet users per 100 individuals, the proportion of urban employees in the computer services and software industry, per capita telecommunications service revenue, the number of mobile phone subscribers per 100 individuals, and the digital financial inclusion index. Standardization of these indicators is performed, followed by dimension reduction using principal component analysis, yielding a composite index representing the level of digital economy development.

3.1.2 Indicator Measurements

In general, there are n evaluation objects and m evaluation indicators, which are represented by the evaluation matrix $Y = (y_{ij})n*m$. Each indicator y_{ij} in the matrix is converted into a standardized indicator x_{ij} by standardization operation. the equation for standardization of indicators is equation (1):

$$x_{ij} = \frac{y_{ij}-\bar{y}_j}{s_j} \quad (i=1,2,\ldots,n; \; j=1,2,\ldots,m) \tag{1}$$

The meanings of the symbols in the formula are as follows: xij denotes the standardized value of the j-th indicator of the i-th evaluation object; y_{ij} denotes the original value of the j-th indicator of the i-th evaluation object, $\bar{y}_j$ denotes the mean value of the j-th indicator; S_j denotes the standard deviation of the j-th indicator; n denotes the number of the evaluation object, and m denotes the number of indicators. In this study, n=369 (i.e., nine years of data for 41 cities in the Yangtze River Delta region) and m=5 (i.e., the five specific indicators that need to be standardized as described in the previous section: the number of Internet broadband access users per 100 people, the share of employees in the computer services and software industry in the number of employees in urban establishments, the total amount of telecommunication services per capita, the number of cell phone subscribers per 100 people, and the index of digital financial inclusion).

Next, the correlation coefficient matrix R of the raw indicators is calculated with the following equation (2):

$$R = [r_{ij}]_{m*m}(i=1,2, \dots .m; j=1,2, \dots, m) \quad (2)$$

where r_{ij} is the correlation coefficient between the original variables x_i and x_j.

The eigenvalue λ of the correlation coefficient matrix R is first calculated and will be ordered from largest to smallest, meaning that $\lambda_1 \geq \lambda_2 \geq \lambda_3 \dots \geq \lambda_m \geq 0$, i.e., the variance of the principal component. Then calculate its corresponding eigenvectors $l_1, l_2, \dots, l_m$, vector l_j shown in equation (3), through the eigenvectors to transform the standardized indicators into m new indicator variables, i.e., m new principal components $f_1, f_2, \dots, f_m$.

$$l_j = (l_{1j}, \ l_{2j}, \ \dots, \ l_{nj})^T \quad (3)$$

The first q principal components with general eigenvalues greater than 1 are selected to replace the original m indicator variables, thus achieving the purpose of dimensionality reduction. At the same time, the variance coefficient of contribution and the cumulative contribution rate of each principal component are calculated. Where the variance contribution rate b_j is shown in equation (4):

$$b_j = \frac{\lambda_j}{\sum_{k=1}^{m} \lambda_k} \quad (4)$$

And the cumulative contribution rate a_q is shown in equation (5):

$$a_q = \frac{\sum_{k=1}^{p} \lambda_k}{\sum_{k=1}^{m} \lambda_k} \quad (5)$$

When the cumulative contribution ratio is close to 1 (i.e., more than 0.8), then the first q principal components, $f_1, f_2, \dots, f_q$, can be selected instead of the m indicator variables. After selecting the principal components, the composite score Z is calculated using equation (6).

$$Z = \sum_{j=1}^{q} b_j y_j \quad (6)$$

Descriptive statistics for specific composite scores are shown in Table 1 below.

3.2 Explanatory Variable

Following Zhong Min's approach [1], this study employs the total export trade of each prefecture-level city, denoted as "*exp*," to gauge the city's level of export trade.

3.3 Control Variables

The mediating variables in the regression model include (1) Foreign Direct Investment (*FDI*): The level of foreign direct investment is crucial in influencing export trade. Drawing from Zhao Tao's research [18], this paper utilizes the actual amount of foreign investment utilized by each prefecture-level city in the given year, logarithmically processed. (2) Degree of Openness(*open*): The extent of a city's openness to the outside world significantly impacts its total export trade. Inspired by Zhong Min's work [1], this study measures a city's openness ratio by dividing its total import and export trade by the city's total GDP for the year. (3) Science Expenditure (*sci*): Yao Zhanqi [3] suggests that science expenditure promotes a city's scientific and technological development, thereby enhancing its production product competitiveness and affecting export trade levels. This paper uses the ratio of a city's science and technology expenditure to its local general public budget expenditure to reflect its science expenditure level. (4) Per Capita Regional Gross Domestic Product (*GDP*): Regional economic development levels, represented by per capita regional GDP, also influence export trade, according to Yin Zhongming [6]. Hence, this variable is chosen as a control variable and logarithmically treated in this paper.

3.4 Data Sources and Processing

Considering data completeness, and availability, and ensuring the regression analysis's validity, this paper focuses on panel data from 2011 to 2019, covering 41 prefecture-level cities in the Yangtze River Delta. The cutoff in 2019 acknowledges the significant impact of the COVID-19 pandemic on total export trade, ensuring robust regression analysis. Additionally, following the State Council's Outline of the Plan for the Integrated Development of the Yangtze River Delta Region, the region is categorized into central and non-central areas. Data are sourced from the China Urban Statistical Yearbook, the National Bureau of Statistics, and the statistical yearbooks of prefecture-level cities.

Table 1. Descriptive statistics of the main variables

Variable	Observations	Mean	Upper Quartile	Standard Deviation	Maximum	Minimum
exp	369	13.429	3.033	27.247	137.209	0.059
dig	369	0.000	-0.434	1.402	5.055	-2.018
FDI	369	2.165	2.224	1.227	5.250	-0.821
open	369	0.304	0.190	0.315	1.813	0.018
GDP	369	10.988	11.043	0.607	12.201	9.219
sci	369	0.034	0.030	0.020	0.131	0.004

4 Econometric Modeling and Empirical Analysis

4.1 Econometric Modeling

In this paper, Equation (7) is set as the baseline model to analyze the relationship between the core explanatory variable *dig* and the explanatory variable *exp*:

$$\mathrm{exp}_{it} = \beta_0 + \beta_1 \mathrm{dig}_{it} + \beta_2 \mathrm{FDI}_{it} + \beta_3 \mathrm{open}_{it} + \beta_4 \mathrm{sci}_{it} + \beta_5 \mathrm{GDP}_{it} + g_i + e_{it} \quad (7)$$

In equation (7) *i* denotes the city, *t* denotes the year, exp_{it} denotes the total export trade of city *i* in year *t*, *dig* denotes the level of digital economic development, *FDI* denotes the level of foreign direct investment, *open* denotes the degree of openness to the outside world, *sci* denotes the level of science expenditure, *GDP* denotes the per capita gross domestic product, g_i denotes the fixed effect on the city, and e_{it} denotes the randomized perturbation term.

4.2 Empirical Test

4.2.1 Analysis of Baseline Regression Results

This paper utilizes panel data analysis to account for both city and year effects on sample individuals. Employing a double fixed-effects model incorporating time and city, the regression analysis is conducted. Table 2 presents the outcomes of the basic regression. Models (1)-(5) progressively integrate control variables, with model (5) representing the final result of this study.

The regression analysis reveals a notable finding: the core variable representing digital development (*dig*) exhibits a consistently positive coefficient at a significant level of 1%. Even with the gradual addition of control variables, the significance and positivity of *dig* remain unchanged. This robustly indicates the significant positive impact of digital development on total export trade, affirming the validity of hypothesis 1. Specifically, for every unit increase in digital development, export trade increases by 3.431 units. This suggests that higher levels of digital economy development correlate with increased digital industrialization and industrial digitization within cities. Digital industrialization facilitates the integration of emerging industries into export trade, broadening market scope and enhancing export trade levels. Moreover, industrial digitization, facilitated by information technologies like the Internet, establishes a resilient trading platform that transcends temporal and spatial barriers, significantly reducing export trade costs and fostering its development.

In the regression results for control variables, several noteworthy findings emerge. Firstly, the coefficient of foreign direct investment (*FDI*) is negatively significant at the 1% level, suggesting a significant inverse correlation with export trade. This could be attributed to the tendency for foreign capital introduction to foster technological dependence, thereby hindering local innovation capacity and impacting export product competitiveness. Secondly, the coefficient of the degree of openness to the outside world (*open*) is significantly positive. This indicates that higher degrees of openness correlate with elevated export trade levels in each prefecture-level city. Furthermore, the coefficient of science expenditure level (*sci*) shows a positive significance at the 5% level. This implies that increased science expenditure moderately enhances export trade levels. Conversely, the coefficient of per capita regional gross domestic product (*GDP*) exhibits negative significance at the 1% level. This suggests that heightened regional economic levels paradoxically reduce export trade levels. This phenomenon may arise from increased local consumption levels accompanying regional economic development, thereby diminishing the need for export trade.

Table 2. Base regression results for model (7)

Variable	(1) exp	(2) exp	(3) exp	(4) exp	(5) exp
dig	2.921***	2.829***	3.579***	3.403***	3.431***
	(0.568)	(0.565)	(0.559)	(0.566)	(0.552)
FDI		-1.326**	-1.821***	-1.926***	-1.835***
		(0.515)	(0.502)	(0.504)	(0.492)
open			11.339***	11.303***	11.946***
			(2.115)	(2.108)	(2.064)
sci				35.475*	43.741**
				(19.683)	(19.325)
GDP					-4.684***
					(1.153)
Constant	119.626***	126.262***	112.581***	112.032***	163.263***
	(2.001)	(3.251)	(4.029)	(4.026)	(13.208)
N	369	369	369	369	369
R^2	0.991	0.991	0.992	0.992	0.992
Year	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes

Note: ***, ***, and ** indicate that the estimates of the parameters are significant at the 1%, 5%, and 10% statistical levels, respectively, and robust standard errors are in parentheses, as in the following table.

4.2.2 Robust Test

In this paper, various methods will be employed to confirm the robustness of the findings.

4.2.2.1 Robustness Test for Changing Variables

This study revisits the measurement of the digital economy level, drawing insights from Zhao Tao [21], Tang Yaojia [4], and others, using the entropy method. The core explanatory variables in the original model are substituted with the new digital development level, *dig2*. Regression results subsequent to this substitution are presented in columns (1) and (2) of Table 3. The findings in the table indicate that even after replacing the core explanatory variables, the level of digital economic development, *dig2*, remains significantly positive at the 1% level. This reaffirms previous findings that the digital economic development of each prefecture-level city significantly enhances export trade levels, demonstrating the robustness of the results.

Table 3. Regression results for robustness tests

Variable	(1) exp	(2) exp	(3) exp	(4) exp	(5) exp	(6) exp	(7) exp
dig	3.431***		2.729***	4.499***	3.403***		
	(0.552)		(0.644)	(0.791)	(0.624)		
L.dig						3.736***	
						(0.592)	
L2.dig							1.990***
							(0.710)
FDI	-1.835***	-1.775***	-0.786	-1.448**	-1.448**	-1.943***	-1.764***
	(0.492)	(0.487)	(0.529)	(0.678)	(0.572)	(0.556)	(0.648)
open	11.946***	12.196***	20.448***	-0.077	16.577***	12.180***	8.108**
	(2.064)	(2.039)	(2.666)	(4.034)	(2.509)	(2.494)	(3.369)
sci	43.741**	41.694**	6.402	57.020***	13.855	40.782**	58.876***
	(19.325)	(19.112)	(17.553)	(21.874)	(21.086)	(20.334)	(22.520)
GDP	-4.684***	-4.694***	-5.662***	-2.649	-5.363***	-4.213***	-4.474***
	(1.153)	(1.140)	(0.871)	(1.659)	(1.175)	(1.179)	(1.301)
dig2		35.518***					
		(5.197)					
Constant	163.263***	153.629***	160.234***	146.663***	163.798***	158.589***	170.477***
	(13.208)	(13.309)	(10.223)	(20.407)	(13.534)	(13.793)	(15.574)
N	369	369	205	246	287	328	287
R^2	0.992	0.992	0.997	0.995	0.994	0.993	0.993
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes	Yes

4.2.2.2 Robustness Test by Time Interval

To ensure robustness, we divided the sample into three groups with varying time intervals for separate regression analyses, as depicted in columns (3) to (5) of Table 3. Specifically, column (3) spans from 2013 to 2017, covering 5 years; column (4) encompasses 2014 to 2019, totaling 6 years; and column (5) represents 2012 to 2018, amounting to 7 years. Our analysis demonstrates consistent findings across these time intervals, indicating the stability of the regression results.

4.2.2.3 Endogeneity Test

To test the robustness of the findings, this paper incorporates lag one and lag two of the digital economic development level as explanatory variables in the regression, as shown in models (6) and (7) of Table 3. The results from the table remain significant and align with those of the benchmark regression, affirming the robustness of the outcomes.

4.2.3 Influence Mechanism Test

This paper aims to validate the mechanism of industrial agglomeration based on the theoretical analysis presented earlier, specifically testing research hypotheses 2 and 3. To achieve this, the following analysis employs a stepwise regression method to examine the mediating effect model. Drawing on the approach of Song Deyong [37], the degree of industrial agglomeration in each city is measured by the ratio of (output of the secondary industry + output of the tertiary industry) to the city's land area for construction. The mediating effect model is outlined as follows:

$$\mathrm{exp}_{it} = \beta_0 + \beta_1 \mathrm{ind}_{it} + \theta \mathrm{j}_{it} + \mathrm{g}_i + \mathrm{e}_{it} \tag{8}$$

$$\mathrm{ind}_{it} = \alpha_0 + \alpha_1 \mathrm{dig}_{it} + \theta \mathrm{j}_{it} + \mathrm{g}_i + \mathrm{e}_{it} \tag{9}$$

$$\mathrm{exp}_{it} = \rho_0 + \rho_1 \mathrm{ind}_{it} + \rho_2 \mathrm{dig}_{it} + \theta \mathrm{j}_{it} + \mathrm{g}_i + \mathrm{e}_{it} \tag{10}$$

In equations (8) ~ (10), the meaning of the same variables is consistent with the baseline regression model, *i* denotes the city, *t* denotes the year, ind_{it} denotes the degree of industrial agglomeration of the prefecture-level city *i* in year *t*, θj_{it} is the set of control variables, g_i is a fixed effect, and e_{it} is the random perturbation term.

Table 4. Result of mechanism of action test

Variable	(1) exp	(2) ind	(3) exp
dig	3.431***	105.120***	2.994***
	(0.552)	(21.746)	(0.566)
FDI	-1.835***	-17.089	-1.764***
	(0.492)	(19.377)	(0.487)
open	11.946***	-647.554***	14.637***
	(2.064)	(81.235)	(2.235)
sci	43.741**	-565.808	46.093**
	(19.325)	(760.695)	(19.112)
GDP	-4.684***	91.473**	-5.064***
	(1.153)	(45.380)	(1.146)
Ind			0.004***
			(0.001)
Constant	163.263***	489.872	161.227***
	(13.208)	(519.907)	(13.069)
N	369	369	369
R^2	0.992	0.955	0.992
Year	Yes	Yes	Yes
City	Yes	Yes	Yes

The mediation effect results are presented in Table 4. Columns (1), (2), and (3) correspond to the estimation results of models (8), (9), and (10), respectively. In column (2), the regression results indicate that the coefficient of "*dig*" is positively significant at the 1% level. This suggests that an increase in the digital economy's development level by 1 unit results in a substantial increase of 105.120 units in the degree of industrial agglomeration. This finding validates hypothesis 2, demonstrating that the digital economy effectively fosters industrial agglomeration in prefecture-level cities within the Yangtze River Delta region. Moving to column (3), the regression result shows that the coefficient of "*ind*" is also positively significant at the 1% level. This implies that for every one-unit increase in the city's industrial agglomeration degree, the export trade level of the city increases by 0.004 units. This underscores the significant positive impact of industrial agglomeration on export trade levels.

Based on the results of the stepwise regression method, the degree of industrial agglomeration acts as a mediator between the level of digital economy development and the level of export trade. The coefficients of the explanatory variable "dig" in both column (3) and column (1) are positively significant at 1%, indicating that industrial agglomeration partially mediates in this model. The level of digital economy development positively influences export trade by promoting industrial agglomeration. It is noteworthy that after adding the industrial agglomeration ("*ind*") variable in column (3), the coefficient of the core explanatory variable "*dig*" remains positively significant, indicating a positive effect. However, the coefficient value becomes significantly smaller, further confirming the mediating effect of industrial agglomeration and establishing Hypothesis 3.

4.2.4 Heterogeneity Test

Cities across different geographic locations may exhibit variations in the level of digital economy development, the magnitude of export trade, and policy priorities set by local governments. To delve deeper into whether the influence of the digital economy on export trade varies across cities with diverse geographic positions, this study partitions the Yangtze River Delta region into central and non-central regions based on geographical considerations and national directives. The central region encompasses 27 cities, including prominent urban centers like Shanghai and Suzhou, outlined in the "Outline of the Plan for the Integration and Development of the Yangtze River Delta Region" issued by the State Council. Conversely, the remaining 14 cities constitute the non-central area. Table 5 presents the regression findings.

Table 5. Result of heterogeneity test

Area	**(1) Central Area**	**(2) Non-Center Area**
dig	3.151***	0.340
	(0.739)	(0.265)
FDI	-2.544***	-0.112
	(0.700)	(0.170)
open	13.713***	8.636***
	(2.539)	(1.803)
sci	32.116	-0.032
	(23.899)	(12.668)
GDP	-5.515***	0.054
	(1.647)	(0.472)
Constant	174.943***	-0.421

	(18.744)	(5.038)
N	243	126
R^2	0.992	0.888
Year	Yes	Yes
City	Yes	Yes

The regression results indicate a significant positive coefficient for the level of digital economy development in the central region, aligning with previous findings. However, neither the digital economy development nor the export trade level in the non-central region passes the significance test. This discrepancy may stem from the central region's advantageous policy environment, superior infrastructure, and abundance of IT talent compared to non-central cities. As outlined in the "Outline of the Plan for the Integrated Development of the Yangtze River Delta Region" by the State Council, the central region is a focal point for national development efforts within the Yangtze River Delta. Its advanced economic status and earlier digital economy development contribute to a more substantial impact on export trade. Conversely, the non-central region faces challenges such as inadequate infrastructure and technology, potentially exacerbated by competition from neighboring central cities for high-value export products. Consequently, both the digital economy and export trade levels remain relatively low in non-central areas, limiting the digital economy's influence on export trade.

5 Conclusion

This paper delves into the impact and underlying mechanisms of the digital economy on export trade using panel data from the Yangtze River Delta region spanning 2011 to 2019. The following conclusions emerge: Firstly, the digital economy significantly boosts export trade growth in the Yangtze River Delta, a finding corroborated by robustness tests, including transformations using entropy weight methods. Secondly, mechanism testing reveals that industrial agglomeration serves as a vital conduit through which the digital economy drives export trade in the region. Thirdly, heterogeneity analysis demonstrates that the digital economy's positive impact on export trade is more pronounced in the central region of the Yangtze River Delta, whereas in the non-central region, its effect is mitigated by competition dynamics, economic disparities, and infrastructure deficiencies. In light of these findings, this paper offers the following recommendations.

5.1 Governmental Perspective

Firstly, to address the development disparity in the YRD region, the government must implement robust resource management strategies. This entails fostering balanced growth and reducing the discrepancy between central and non-central regions in terms of digital economy and export trade. Specifically, targeted policies like tax incentives, financial aid, and land use concessions can entice digital economy and export trade enterprises to relocate to non-central areas. Furthermore, offering financial support and technical guidance can encourage traditional industries in these regions to undergo digital transformation, boosting their value and adaptability to the digital economy's demands. Consequently, this approach can generate more job opportunities, spur investment, bolster the overall competitiveness of non-central areas, and foster balanced development across the YRD region.

Secondly, it's imperative to advance the digital economy, elevating its stature and reach within the Yangtze River Delta (YRD) region. The government can play a pivotal role by bolstering digital infrastructure, including 5G networks, fiber optics, and cloud data centers, through public investment or government-backed initiatives. By actively sponsoring research and development programs, financial support can be allocated to critical digital infrastructure projects. Additionally, the formulation of preferential policies can incentivize enterprises and private entities to contribute to this infrastructure. To ensure seamless implementation, clear standards and norms should be established, guided by proactive government oversight. Such initiatives not only expedite digitalization within the YRD region but also on a national scale. They pave the way for a robust information transmission network, enhancing China's competitive edge in global trade.

Thirdly, addressing the noteworthy negative correlation between foreign direct investment (FDI) and export trade in the previous section underscores the imperative for the Yangtze River Delta (YRD) region to reduce its reliance on foreign investment. Prioritizing local innovation and bolstering the investment climate is essential. The government can establish a dedicated fund to support local enterprises in scientific research, development, and innovation, thus enhancing their capacity for independent innovation and diminishing the need for foreign technological imports. Simultaneously, fostering local brands to augment their market presence can reduce dependence on foreign counterparts. Streamlining administrative procedures and lowering market entry barriers are equally vital measures to enhance the investment climate. This will attract more domestic enterprises, alleviating financial pressures on local innovation. Additionally, establishing industrial parks offering comprehensive services like office space, research and development facilities, and production units can encourage enterprise clustering and foster a robust industrial ecosystem. Leveraging the developed areas within the YRD region can attract high-quality enterprises and professionals, further fortifying the region's economic landscape.

5.2 Enterprise Perspective

Firstly, enterprise digital transformation represents an inevitable trajectory for future development. To commence this journey effectively, enterprises must initially delineate their transformation goals, which may include enhancing productivity, optimizing customer experiences, and curbing operational costs. Clear objectives facilitate meticulous planning and execution of digital initiatives. Recognizing that each enterprise possesses unique characteristics and requirements, selecting the most appropriate digitalization pathway, technology, and management model becomes paramount for success. Digital transformation is a continual endeavor, necessitating regular assessments and adjustments based on real-world outcomes. Leveraging various IT tools such as ERP and CRM systems can streamline business processes, boosting efficiency and reducing errors. Moreover, it's imperative to acknowledge that digital transformation transcends technological shifts—it entails a cultural overhaul within organizations. Hence, enterprises must prioritize employee training and education to foster a culture of acceptance and proficiency in utilizing new tools and methodologies.

Secondly, enterprises in the YRD region should proactively foster industrial agglomerations, particularly within the digital technology sector, to drive export trade. As highlighted earlier, industrial agglomeration plays a pivotal role in boosting export trade in the region. Enterprises can forge industrial alliances with counterparts in similar or complementary industries, facilitating agglomeration through resource pooling, knowledge sharing, and collaborative R&D endeavors. Leveraging the resource integration capabilities of the digital economy, firms can optimize supply chain networks by integrating suppliers, manufacturers, distributors, and other stakeholders into cohesive industrial clusters. Moreover, heightened investment in product innovation and the continual introduction of competitive offerings serve as effective means to attract additional collaborators. Furthermore, establishing partnerships with universities and research institutions enables participation in joint R&D initiatives, fostering deeper industry-academic collaboration. This, in turn, enhances enterprise visibility and reputation, thereby attracting more local enterprises to engage in cooperative ventures and aggregation.

To effectively foster the development of the digital economy in the YRD, collaborative efforts between governments and businesses are paramount. Through coordinated initiatives encompassing policy support, infrastructure development, innovation, and cooperation, the region can emerge as a hub for digital innovation and export growth. However, ongoing monitoring, evaluation, and adaptation of policies and strategies are essential to sustain and enhance the effectiveness of these collaborative measures in the future.

Acknowledgments. This research was supported by the Master's Degree Innovation Program Project at Chongqing University of Science and Technology, under the grant titled "Mechanism and Empirical Research on the Influence of Digital Economy on Export Trade in Yangtze River Delta Region" (Project No. YKJCX2321001).

References

[1] Zhong, M., & Wang, Z. T. Digital Economy and Export Growth: A Study Based on Chinese City and Customs Data. International Trade Exploration, 38(09), 21-37 (2022)

[2] Yang, H. M., & Jiang, L. Digital Economy, Spatial Effects, and Total Factor Productivity. Statistical Research, 38(04), 3-15. (2021)

[3] Yao, Z. Q.. The Impact of the Digital Economy on China's Manufacturing Export Competitiveness and Its Threshold Effect. Reform, (02), 61-75(2022)

[4] Tang, Y. J., Wang, Y., & Tang, C. H. Digital Economy, Market Structure, and Innovation Performance. China Industrial Economics, (10), 62-80(2022)

[5] Fan, X. Digital Economy and Exports: An Analysis Based on Heterogeneous Stochastic Frontier Models. World Economic Research, (02), 64-76+135(2021).

[6] Yin, Z. M., Shi, Z. C., & Wang, J. Q. The Impact of the Digital Economy on China's Manufacturing Export Structure. Finance and Economics Science, (12), 132-145(2023)

[7] Yao, Z. Q. The Multiple Effects of the Digital Economy on China's Foreign Trade Competitiveness. Research on Financial and Economic Issues, 458(1), 110-119(2022)

[8] Chiappini, R., & Gaglio, C. Digital intensity, trade costs, and exports' quality upgrading. The World Economy, 1(2023)

[9] Choi, C. The Effect of the Internet on Service Trade. Economics Letters, 109(2), 1-104(2010)

[10] Tao, A. P., & Zhang, Z. The Impact of the Digital Economy on the Development of Service Trade: An Empirical Study Based on National Panel Data. East China Economic Management, 36(05), 1-14(2022)

[11] Meng, X. H., & Xu, J. Evaluation of the Development Index of Digital Service Trade and Analysis of Its Influencing Factors: A Panel Data Analysis of 50 Countries. Inquiry into Economic

Issues, (10), 170-190(2023)
[12] Zhang, M. H. Research Progress on International New Economic Measurement and Its Enlightenment to China. Economist, 2017(11), 47-55(2017)
[13] He, F., & Liu, H. X. Evaluation of Performance Improvement Effect of Digital Transformation of Entity Enterprises from the Perspective of Digital Economy. Reform, (04), 137-148 (2019)
[14] Zhang, X., Yang, Z., & Tan, Y. Digital Economy, Division of Household Labor, and Gender Equality. Economic Quarterly, 23(01), 125-141(2023)
[15] Fan, X. Development of Digital Economy, Efficiency of International Trade, and Trade Uncertainty. Finance and Trade Economics, 41(08), 145-160 (2020)
[16] Chen, F. Z. Digital Economy, Trade Openness, and Economic Growth of Countries along the "Belt and Road". Lanzhou Academic Journal, (11), 100-112(2020)
[17] Bai, P. W., & Zhang, Y. Digital Economy, Decline in Population Dividend, and Rights of Low-skilled Workers. Economic Research, 56(05), 91-108(2021)
[18] Zhao, T., Zhang, Z., & Liang, S. K. Digital Economy, Entrepreneurial Activity, and High-Quality Development: Empirical Evidence from Chinese Cities. Management World, 36(10), 65-76 (2020)
[19] Liu, J., Yang, Y. J., & Zhang, S. F. Research on the Measurement and Driving Factors of China's Digital Economy. Shanghai Economic Research, (06), 81-96(2020)
[20] Amuso, V. The Digital Economy: Opportunities and Challenges. Global Policy, 2020(11), 124-127(2020)
[21] Cheng, D. N., & Jin, M. The Influence Mechanism of Informatization on the Export Behavior of Chinese Manufacturing Enterprises. Henan Social Sciences, 28(12), 71-83 (2020)
[22] Li, D., Wu, T., & Wang, H. F. Digital Technology Investment and Local Market Effects in Manufacturing Industry. International Trade Issues, (01), 32-49(2024)
[23] Chen, W. T., & Tang, Z. W. The Impact and Mechanism of Digital Technology Application on the Export Competitiveness of Chinese Enterprises. East China Economic Management, 1-11 (2024)
[24] Shen, H. B., & Deng, F. H. Research on the Influence of Digital Infrastructure Construction on Export Industry Upgrading. China Soft Science, (12), 59-69(2023)
[25] Ju, X. N., Zhao, X. K., & Sun, B. W. What Trade Costs Did Cross-border E-commerce Platforms Overcome? Empirical Evidence from "Dunhuang.com" Data. Economic Research, 55(02), 181-196(2020)
[26] Ma, S. Z., Fang, C., & Zhang, H. S. Can Cross-border E-commerce Break Through the Restriction of Geographic Distance? Finance and Trade Economics, 40(08), 116-131(2019)
[27] Li, X. P., Yu, J. J., Yu, D. S., & Wu, J. H. Cross-border E-commerce and Product Upgrading in Enterprise Exports. Economic Research, 58(01), 124-140 (2023)
[28] Zhang, H. S., Pan, G. J., & Zhang, Y. Cross-border E-commerce and Bilateral Trade Costs: Empirical Research Based on Cross-border E-commerce Policy. Economic Research, 56(09), 141-157 (2021)
[29] Mao, F. F., Gao, Y. C., & Zhou, C. Evolution of the Spatial Pattern of Digital Industry in the Yangtze River Economic Belt and Its Driving Factors. Geographical Research, 41(06), 1593-1609(2022)
[30] Zhao, F., Li, W. T., & Ma, W. Y. Evolution Characteristics and Coupling Relationship between Geographic Agglomeration and Virtual Agglomeration in the Perspective of Digital Economy. Journal of Jilin University Social Sciences, 64(01), 117-132+238 (2024)
[31] Zhou, J., & Wang, H. Digital Economy, Industrial Synergy Agglomeration, and Urban Green Innovation. Technological Economics and Management Research, (01), 66-71(2024)

[32] Ren, J., Zhao, R. R., & Ren, J. H. Digital Finance, High-tech Industry Agglomeration, and Regional Innovation Performance. Statistics and Decision, 39(05), 86-91(2023)
[33] Liu, H. D., & Chen, X. S. Can Export Trade Efficiency be Improved from Agglomeration Economy? Empirical Test Based on Provincial Panel Data in China. Journal of Beijing Technology and Business University (Social Sciences), 31(06), 43-54(2016)
[34] He, C. F., Ren, Z. R., & Ye, Y. L. Industrial Geographic Agglomeration in China and Regional Export Economic Complexity. Geographical Research, 40(08), 2119-2140(2021)
[35] Sun, C. R., Yu, H., & Zhao, R. L. Can Urban Export Product Quality be Improved from Agglomeration Economy? International Trade Issues, (07), 23-32(2014)
[36] Pan, K., He, F., & Liu, R. Does High-Tech Industry Agglomeration Promote Its Export Product Upgrading?—Based on the Perspective of Innovation and Openness. Sustainability, 14(13), 8148-8148(2022)
[37] Song, D. Y., Li, C., & Li, X. Y. Does the Construction of New Infrastructure Promote the "Quantity and Quality Rise" of Green Technology Innovation? Evidence from National Smart City Pilot Projects. Population, Resources and Environment in China, 31(11), 155-164(2021)