

An Empirical Analysis of the Digital Economy's Impact on Regional Export Efficiency: Evidence from RCEP Countries and Zhejiang, China

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Abstract

This research paper constructs an indicator system for measuring the level of digital economy development of RCEP countries. Based on the panel data of export trade of Zhejiang Province to RCEP countries from 2012 to 2022, using the stochastic frontier gravity model (SFGM), it systematically evaluates the influence of digital economy of RCEP countries on export efficiency of Zhejiang Province, revealing the crucial role of digital economy in promoting international trade through multi-dimensional and multi-level data analyses. The results of the research imply that the improvement in digital economy of RCEP countries significantly contributed to export efficiency of Zhejiang Province, with differences between different dimensions of digital economy. During the study period, the export efficiency of Zhejiang Province to ASEAN countries increased the most. Therefore, it is suggested to strengthen the RCEP digital economy circle, adopt different strategies for cooperation and connection, as well as focus on the changes and opportunities in the ASEAN market. This study provides valuable insights for policy makers and stakeholders and is of great practical importance for enhancing economic and trade cooperation among RCEP countries.

Keywords: digital economy, RCEP countries, stochastic frontier gravity model, export efficiency, Zhejiang Province

1. Introduction

Digital economy is driving the global technological revolution as part of the wave of global economic integration. And it has become a major force in changing the global competitive landscape. According to the Global Digital Economy White Paper (2024) released by the China Academy of Information and Communications Technology (CAICT), the digital economy of five countries - the United States, China, Germany, Japan and South Korea – is estimated to total more than \$33 trillion in 2023 and account for 60 percent of GDP, with a year-on-year growth of more than 8 percent. Thus, the digital economy has become an integral component of the global economy and has a profound impact on the stability of its growth.

Due to the rapid development of information technology and the widespread application of the Internet, the digital economy has not only given rise to diverse business models and industrial forms, but has also greatly contributed to the facilitation and efficiency of international trade. The Regional Comprehensive Economic Partnership (RCEP), the world's most populous free trade zone with the most diversified membership structure and the greatest potential for development, has become increasingly influential in reshaping global trade patterns. It covers the 10 ASEAN countries as well as other major economies in the Asia-Pacific region, including China, Japan, South Korea, Australia, and New Zealand. Furthermore, it provides new opportunities for economic cooperation and trade exchanges among member countries through measures such as lowering tariff barriers and promoting the liberalization and facilitation of trade and investment. Since the RCEP agreement came into effect on January 1, 2022, the vibrant nature of digital technology in conjunction with the global trade creation effect generated by the world's largest free trade area has enabled the RCEP region, which has the advantages of scale and system, to realize trade innovation in the field of digital economy, and ultimately become a pole of economic growth regionally and globally.

Located on the eastern coast of China, Zhejiang Province, which is a large economic region, plays a pivotal role in the promotion of economic growth of China, industrial upgrading, and employment expanding through its exports. Given the new opportunities brought by the RCEP agreement, how Zhejiang Province can further improve export efficiency while ensuring stable export growth has become an urgent issue for the development of foreign trade in Zhejiang Province. Therefore, under the framework of RCEP, it is particularly important to study the impact of digital economy on export efficiency, particularly for regions with high foreign trade dependence such as Zhejiang Province.

Thus, taking the high point in digital economy development and the entry into force of RCEP agreement as an important opportunity, this study empirically examines the impact of digital economy on export efficiency with Zhejiang Province and RCEP countries as the research subjects. It is expected to provide strong theoretical support and practical guidance for promoting economic and trade exchanges, optimizing trade structures and enhancing export efficiency between Zhejiang Province and RCEP countries, as well as provide useful references and inspiration for other countries and regions. Additionally, this study is of substantial practical significance for the construction of the RCEP digital economic circle and for the advancement of economic cooperation among member states. As for the remainder of the paper, it is arranged as follows. Section 2 reviews the state-of-the-art literature, emphasizing the area that has been overlooked in previous research. Section 3 provides a theoretical analysis that can be used to guide empirical investigations, including the definition of the digital economy and its effects on international trade. And on this basis Section 4 analyzes the current trade situation between Zhejiang Province and RCEP countries and measures the digital economy in RCEP countries. Section 5 introduces the models used in the paper. Section 6 presents the empirical results and discussion of the multi-dimensional and multi-level effects of digital economy on export efficiency. Finally, the conclusions and countermeasures are presented in Section 7.

2. Literature Review

This paper reviews and comments on three aspects of literature related to the research theme: first, studies on digital economy; second, studies on trade efficiency and trade potential; and third, studies related to the relationship between digital economy and international trade.

2.1 Digital Economy

In addition to being a new type of economic form [1], digital economy is one of the most important driving forces for innovation and inclusive growth in the global economy [2]. Since Tapscott [3] first proposed the concept of digital economy, a wave of attention has been paid to digital economy at home and abroad, including its connotation, characteristics, measurement and socio-economic effects.

2.1.1 Concept of Digital Economy

Digital economy represents a global system of economic activities enhanced by information and communication technology (ICT) [4]. Digital revolution was triggered by the massive use of ICTs [5], which was characterized by technological advances. The definition and scope of digital economy have evolved over time with the advancement of mainstream technologies (e.g., the Internet, artificial intelligence, robotics) at different times [6].

Both domestic and foreign scholars agreed that digital economy in the broad sense is defined as entire economic output produced by a variety of digital technology inputs [7], encompassing the construction of ICT infrastructure, the use of ICTs for economic activities [8, 9], and the content created and accessed by digital economy users [10]. Additionally, some scholars defined digital economy as productive modern services aimed at providing efficiency enhancement and structural optimization of economic activities [11], which contributes to the improvement of all economic, social, and governmental activities of human life [12].

According to the Digital Economy Development and Cooperation Initiative issued by G20 Digital Economy Task Force (DETF), digital economy comprises a wide range of economic activities based upon the use of digitized information and knowledge as the primary factor of production, modern information networks as a critical activity space, and the effective application of ICT as a powerful driver of economic growth and structural optimization [13]. Compared with traditional economy, digital economy is a consequence of industrialization and marketization of information technology revolution. It has unique advantages in reducing transaction costs, enhancing information transmission speed and maximizing economic resources allocation [14]. Further, Zhang [15] pointed out that the technical attributes and extensive permeability of digital economy can effectively boost the transformation and upgrading of industrial structure.

2.1.2 Measurement of Digital Economy

Generally, studies on the measurement of digital economy are designed to assess the scale or competitiveness of digital economy in a certain region, and are categorized into two types. First, statistical measurement of the total scale of digital economy. The Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce measured the current-dollar value added of the digital economy in the US by defining the concept and scope of digital economy [10]. The China Academy of Information and Communication Technology (CAICT) identified key indicators such as outputs related to digital economy to reasonably estimate the size of the digital economy in China [16]. Ahmad and Ribarsky [17] examined the shortcomings existing in the data accounting process of the traditional national economic accounting system and put forward suggestions for the measurement of digital economy. According to Guan et al. [18], the digital economy industry in China was statistically classified into digital equipment manufacturing, digital information transmission, etc.

The second area of research related to the measurement of digital economy focuses on the compilation of indices relevant to digital economy. The European Commission has tracked the progress in the digital economy of member states and published annual Digital Economy and Society Index since 2014 [19]. In order to construct a digital economy indicator system, the Organization for Economic Cooperation and Development (OECD) selected 38 globally comparable indicators based on four dimensions: smart infrastructure investment, social empowerment, innovation capacity, and ICT application and diffusion [20]. Meanwhile, researchers at home and abroad have proposed empirical studies such as digital economy measurement and digital economy development index based on diversified connotations of digital economy. There were three main measurement dimensions. Firstly, it was the fundamental conditions required for the development of digital economy, including digital infrastructure [21] and digital industrialization [22, 23]. Secondly, it was the external environment for the development of digital economy, such as economic conditions [24], policy support [25], technological innovation [26], and governance environments [27]. Finally, it was the integrated application of digital economy with the primary, secondary, and tertiary industries [27], which was the landing point of the development of digital economy. Digital economy was most widely applied in the service industry, such as e-commerce [22], digital inclusive finance [21], etc. Industrial digitalization involved application operating software, industrial e-commerce platform, industrial internet platform, etc. [28]. Agricultural digitalization was slower compared to the digitalization of industry and services. In addition, it was important to consider specific characteristics of developing countries when developing measurement standards for digital economy [12].

At present, digital economy is still defined and measured differently in domestic and international studies. The differentiation of measurement indicators and the diversity of data sources will affect the accuracy and validity of quantitative estimates of digital economy.

2.1.3 Socio-economic Effects of Digital Economy

Digital economy and traditional economy overlapped and interwove with each other [12]. Scholars examined the impact of digital economy on economic growth [29], industrial transformation [30], the real economy [31], regional innovation capacity [32], and regional integrated development [33]. And it was found that digital economy can boost productivity and enterprise innovation [34], support high-quality economic development [35], as well as enhance sustainable regional development [21]. Developing countries had new opportunities to catch up with developed countries in digital economy [36].

2.2 Trade Efficiency and Trade Potential

With the process of economic globalization, it has become increasingly difficult for countries to compete in the international markets in recent years. The existence of trade protectionism in some countries has seriously hampered trade exchange. Scholars have focused on the efficiency and potential of international trade, which is a crucial indicator for measuring trade cooperation between countries. The existing literature is mainly concerned with measuring trade potential and trade efficiency as well as analyzing the factors influencing international trade efficiency.

2.2.1 Measurement of Trade Potential and Trade Efficiency

Typically, the trade gravity model was used to estimate trade potential and trade efficiency in the existing literature. The trade gravity model was derived from Newton's Law of Universal Gravitation, and was pioneered by Tinbergen [37] and Pöyhönen [38] with regard to international trade. In the gravity model, the mass represents economic mass (GDP), whereas the gravity force represents the total amount of trade flows. Thus, bilateral trade was explained by the trade gravity model as a function of the economic size of two countries (measured by their GDPs) and their geographic distance. Subsequently, economists improved the basic model by incorporating the

impact of product complementarity on bilateral trade [39]. Furthermore, a few explanatory variables were added to the trade gravity model for empirical research. For instance, exchange rate [40], language [41], population [42], territorial border [43], trade integration index [44], per capita resource endowment [45], colonies and free trade agreements (FTAs) [46], etc.

However, it has been questioned in some studies. Armstrong [47] argued that the former trade gravity model assumes the mean value of unobservables is zero in empirical studies or substitutes the overall trade resistance with the “iceberg” transportation cost, which fails to account for human inefficiency factors on trade and thus biases the estimation results. In this context, the stochastic frontier analysis method was introduced into the trade gravity model. When estimating the trade frontier, the original variables (such as economic size and geographical distance) as well as natural factors (including language, contiguity, complementarities, etc.), which remain constant in the short and medium term, are usually set as the core variables of the model. In this regard, trade potential is defined as the maximum value that can be achieved by frictionless trade with only natural barriers [48] rather than the average effect of various trade determinants estimated by the traditional trade gravity model.

Up to now, most scholars have studied trade efficiency and trade potential at the national level using the SFGM in the context of specific regional trade agreements [49, 50], however very few studies are available at the inter-provincial level.

2.2.2 Factors Affecting Trade Efficiency

Trade efficiency captures human factors that affect trade performance [51]. There is a need to conduct research on factors that influence trade efficiency in order to improve it. Armstrong [47] suggested that human factors such as trade agreements, tariffs, institutions, logistics [52], trade infrastructure [53], etc., which are easy to change in the short term, should be included in the trade inefficiency term to be examined. Following this, trade inefficiency model should be constructed to analyze trade efficiency factors. Researchers had different settings for exogenous variables in the SFGM. But to sum up, the main considerations revolved around regional integration [54], freedom level [42], trade facilitation [55], etc. And few studies used digital economy in importing countries as an explanatory variable.

2.3 *The Relationship Between Digital Economy and International Trade*

A revolution in technology has accelerated the integration of digital technology into all levels of society and economy. This has resulted in the digital economy being one of the most innovative, dynamic, and widely diffused economic forms. Research on the relationship between digital economy and international trade has also become a popular area in current academic community. Numerous domestic and foreign publications have investigated the effect of digital economy on international trade from the perspective of Internet, ICT, and e-commerce. Based on the theory of trade costs, scholars generally believed that the development and application of the Internet [56], as well as ICT [57] can reduce trade costs and promote export growth. Moreover, e-commerce effectively broadens product variety of export enterprises, geographic scope, and number of destination countries by influencing their production, R&D, and sales processes [58].

Recently, scholars have also examined the impact of the digital economy on trade at the national, provincial, industrial, and enterprise levels. The development of digital economy was a crucial factor in increasing domestic export and export growth [59], with characteristics of regional heterogeneity [60]. Zhong and Wang [61] verified the positive effect of digital economy on urban trade. The development of digital economy contributed to the improvement of provincial-level export technology complexity [62] and urban export quality [63], both of which have significantly influenced the high-quality development of manufacturing export [64, 65] and agricultural export [66]. In terms of the research at the enterprise level, Li and Li [67] found that the Internet would assist enterprises in efficiently entering the export market.

However, some scholars also noted that digital economy is both an opportunity and a challenge for international trade. For instance, digital economy would increase global market competition, lead to greater uncertainty in export [68], decrease international trade profits [69], and negatively affect development countries [56].

In summary, scholars from different countries have conducted extensive research on digital economy. However, they have yet to form a unified standard on the connotation and measurement of digital economy. Moreover, there is a considerable amount of existing research regarding the relationship between digital economy and international trade, but the majority of it focuses on the impact of digital economy on the growth of export, export competitiveness, and export quality. There are several research models and model construction methods proposed by scholars at home and abroad for the analysis of trade efficiency and trade potential of two countries, which provide a basis for future research. Since RCEP was officially signed and implemented, few empirical researches

have been conducted on the effects of digital economy of RCEP countries on the trade efficiency of exporting countries. Particularly, there is virtually no empirical evidence on the economic and trade exchanges between RCEP countries and exporting countries at the provincial level.

Therefore, this study has three aims. Firstly, to analyze the connotation and characteristics of digital economy as well as the mechanism of its impact on international trade from a theoretical standpoint. It is an attempt to improve the theoretical system in the field of digital economy, which is regarded as a more advanced form of economy. Secondly, to construct a digital economy indicator system for RCEP countries and quantify their levels of digital economy. Thirdly, to empirically investigate the effect of digital economy in RCEP countries on export efficiency of Zhejiang Province from multi-dimensional and multi-level perspectives. This study seeks to reveal the critical role of digital economy in promoting international trade and point out the direction for both sides to improve trade structure, enhance trade levels, and formulate economic policies. As well as providing reference for laying the foundation for strengthening, broadening, and deepening cooperation among RCEP countries, it is of great practical importance for enhancing economic and trade relationship within the region.

3. Theoretical Analysis

3.1 Digital Economy

According to the "14th Five-Year Plan for the Development of Digital Economy" issued by the State Council of China (SCC) in December 2021, this paper defines digital economy as a new economic form in which data resources are the key elements, modern information networks are the primary carriers, and information and communication technology integration and application, along with digital transformation of all elements, are the driving forces behind the development of new business modes. And it contributes to greater efficiency and equity [70].

On the basis of the above definition, the digital economy exhibits following characteristics as compared with the traditional economy. (1) In contrast to traditional production factors, such as land, labor, and capital in agricultural and industrial economies, the core production factor of digital economy is data [71, 72]. In more precise terms, it is digitized information resources and professionals and technicians with a solid understanding of digital technologies. (2) Digital economy infrastructure consists of modern information networks powered by both hardware facilities and software technologies. It provides industries with the basis for digital transformation and empowerment, including data storage, sensing, collecting, computation, and transportation, as well as the improvement of total factor productivity. (3) The output of digital economy is data value. This refers to the added value that created by the efficiency enhancement of traditional economy and structural optimization through the innovative integration of data into economic activities. (4) As opposed to the stock allocation system of traditional economy, which rely on land use rights, property rights, and materialized labor as central elements, digital economy is a flow allocation system based on knowledge, technology, creativity, and other potential values of digital talent as the key assets of data rights. This breaks the diminishing marginal benefit effect of production factors of traditional economy in the process of economic growth, facilitates efficient empowerment and non-destructive sharing of data, and creates a value-driven path of "exponential growth".

3.2 Impact Mechanism of Digital Economy on International Trade

(1) Improved digital infrastructure can reduce transaction costs

Due to geographic and cultural distances, information barriers, and institutional constraints, enterprises in exporting countries are required to pay trade costs when entering markets of destination countries [68, 57]. According to transaction cost theory, trade costs are comprised of information search costs, communication costs, credit costs, and institutional costs. In New Economic Geography, trade costs play an important role in the selection of trade locations, spatial agglomeration, and diffusion of economic activity. Moreover, reduced transaction costs are a major contributor to export growth [60]. Digital infrastructure, represented by 5G network, fiber optic broadband, and big data centers, can decrease the cost of information search and communication on both sides of trade [66]. Paperless transactions have become a reality due to the advancement of ICT, which facilitates trade negotiations, contract signing, and export customs clearance in trade, thus reducing contracting cost and institutional cost. Transactions through e-commerce, Internet of Things, and other platforms enhance logistics efficiency, mitigate trade risk and uncertainty, and boost trade efficiency significantly. In this paper, hypothesis 1 is presented on the basis of the above analysis.

H1: Improved digital infrastructure in importing countries can reduce transaction costs and enhance export efficiency.

(2) Industrial digitalization can expand trade market

The digital economy is characterized by a high degree of integration between digital technologies and traditional industries [63]. In the traditional trade mode, the exporter's operation activities are limited by time and space. As the industrial digitalization process continues in the importing country, digital technologies have broken down information exchange barriers, and gradually established a high-efficiency, low-cost, micro-risk digital service system. The high diffusion of digital information solves the problem of information asymmetry between trade subjects, resulting in an accelerated impact on traditional transaction modes, a transformation of market structures, a greater expansion of resource allocation boundaries, and an increase in trade efficiency. The synthesis of digital economy and traditional industries in the importing countries can contribute to the optimization and upgrading of their domestic industrial structure. The change in industrial structure may, to a certain extent, increase the demand for imports of related goods and services, which will help exporting countries broaden the trade market. Based on the above analysis, hypothesis 2 is put forward in this paper.

H2: Industrial digitalization in the importing country helps exporting countries to expand trade markets and enhance export probability.

(3) Digital technology innovation can improve the efficiency of trade matching

Digital economy is a product of the application and innovation of information and communication technology [68]. There is a lack of efficiency in the traditional international trade process, which is lengthy and costly. With the innovative development of digital technology in importing countries, digital platforms have become increasingly important as a form of economic organization emerging in the digital economy. As a result of its immediacy and high degree of sharing, digital platforms facilitate the trade process, improve the availability of information, as well as reduce the cost of information collection for all types of transaction subjects. The widespread implementation of digital technology reduces the barriers to factor flow and the risks and losses caused by resource mismatch [57], thereby enhancing the effectiveness of trade information and the efficiency of factor matching, improving the accuracy of the supply-demand match, and thus improving international trade efficiency [73]. Based on the above analysis, hypothesis 3 is put forward in this paper.

H3: Digital technology innovation in importing countries increases the efficiency of trade matching.

4. Situation Analysis and Measurement

4.1 The Current Situation of Exports from Zhejiang Province to RCEP Countries

4.1.1 Exports of Zhejiang Province as a Percentage of the Country

Zhejiang Province is located on the southeast coast of China. This province has a land area of 1.10%, a population of 4.57%, and a regional GDP of approximately 6.55% of the whole country. Its economy is heavily dependent on international trade. As can be seen in Figure 1, Zhejiang Province was generally on an upward trend with regard to its total exports and its share of the national trade volume from 2012 to 2022. This indicates that Zhejiang Province plays a vital role in the national export growth and has a large economic contribution to the country.

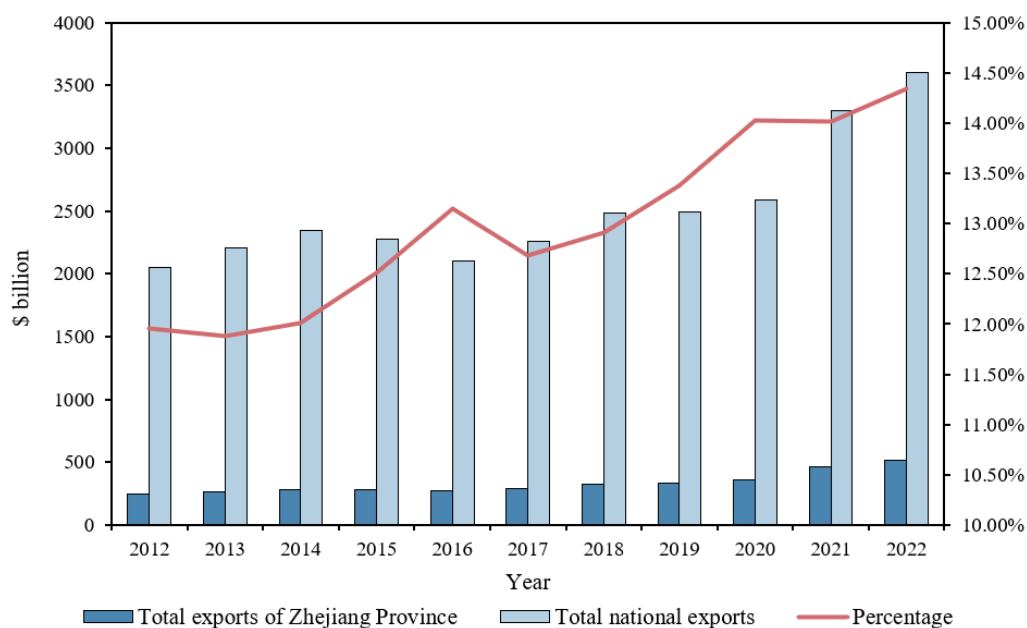


Figure 1. Relationship between total exports of Zhejiang province and total national exports, 2012-2023

4.1.2 Analysis of Trade Between Zhejiang Province and RCEP Countries

According to Figure 2, Zhejiang Province kept increasing its exports to RCEP countries (except China) from 2012 to 2022, reaching \$107.45 billion dollars in 2022, which accounted for 20.83% of the province's total exports. Evidently, RCEP has become one of the province's largest export markets.

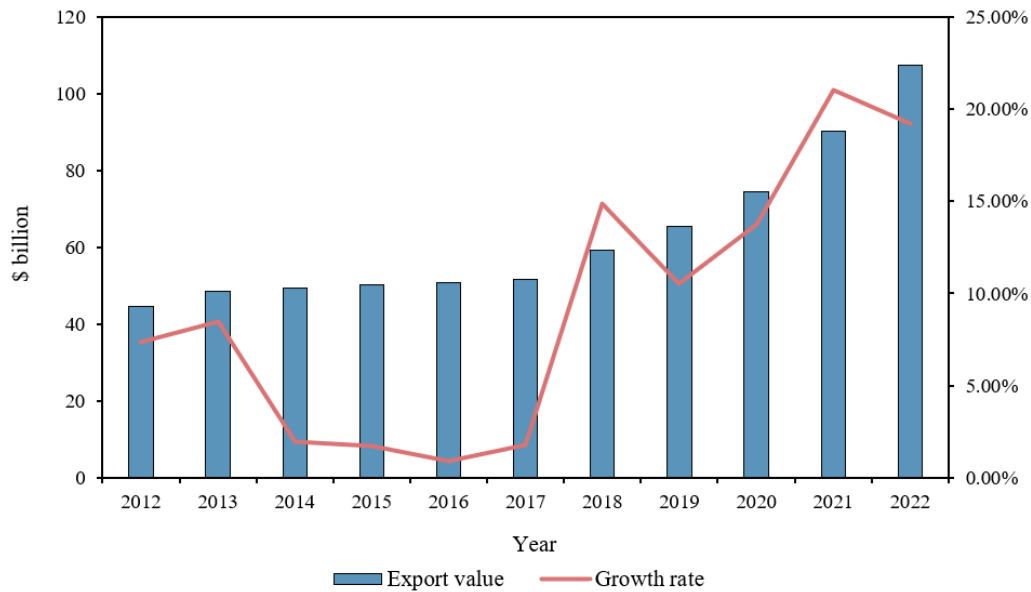


Figure 2. Zhejiang Province's exports to RCEP countries, 2012-2022

Table 1 illustrates that the top three countries in terms of export value of Zhejiang Province in 2022 were Japan, Vietnam, and South Korea. These three countries accounted for more than 40% of all RCEP countries together. This was mainly because of the strong correlation of industrial chain and high economic complementarity among China, Japan and South Korea. Moreover, it was geographically convenient for trade and transportation between Japan, South Korea, and Zhejiang Province. Meanwhile, Vietnam benefited considerably from the friction between China and the United States on economic and trade issues. However, the exports from Zhejiang Province to Brunei and Laos were very low, accounting for only 0.07% and 0.17% of RCEP countries, respectively. This was mainly due to high trade cost between Zhejiang Province and these two countries, which primarily resulted from the small scale of economy, the limited market demand, and the low level of domestic infrastructure.

Table 1. Export value and percentage of Zhejiang Province to RCEP countries, 2022

Country	Export value (\$ million)	Percentage
Japan	15797.122	14.70%
South Korea	13509.213	12.57%
Australia	11299.677	10.52%
New Zealand	1513.557	1.41%
Brunei Darussalam	80.174	0.07%
Cambodia	2535.938	2.36%
Indonesia	12922.771	12.03%
Lao PDR	182.381	0.17%
Malaysia	7761.206	7.22%
Philippines	9170.055	8.53%
Singapore	5523.483	5.14%
Thailand	10777.062	10.03%
Myanmar	1876.918	1.75%
Viet Nam	14497.437	13.49%

In terms of product structure, the exports from Zhejiang Province to RCEP countries were primarily dominated by electromechanical, labor-intensive and high-tech products, which accounted for a large proportion of the industrial output of the province. In the wake of the entry into force of RCEP agreement, the pressure on factor costs such as land and labor, as well as the continuously accelerated upgrading and transformation of the manufacturing industry, have resulted in a trend of the transfer of labor-intensive industries from China to Southeast Asian countries such as Vietnam.

It is noteworthy that the export growth rate of Zhejiang Province to RCEP countries declined from 2014 to 2017, possibly due to exclusivity and trade diversion effects of Trans-Pacific Partnership Agreement (TPP). This situation has improved since the U.S. announced its withdrawal from the TPP in 2017. In particular, the export growth rate increased distinctly after the signing of the RCEP agreement in November 2020.

4.2 Trade Intensity Index

Trade intensity index (TII) was put forward by economist A. J. Brown in 1947 as a measurement of bilateral trade closeness. The formula for calculating TII is as follows:

$$TII_{ij} = \frac{X_{ij}/X_i}{M_j/M_w} \quad (1)$$

Where TII_{ij} represents the TII between regions i and j . When the value of TII is higher, the trade link between the two regions is stronger. X_{ij} represents the export value from region i to region j , X_i represents the total export value of region i , M_j represents the total import value of region j , and M_w represents the total global import value. If $TII_{ij} \geq 1$, it indicates that the two regions are closely linked in trade relationship, and if $TII_{ij} < 1$, it indicates that the two places are loosely linked in trade.

Table 2 shows the TII between Zhejiang Province and RCEP countries in 2012-2022 based on equation (1). It can be observed that Zhejiang Province had relatively close trade relations with RCEP countries in 2012-2022. Cambodia, Indonesia, the Philippines, Vietnam and Myanmar were the countries with the greatest trade intensity, all of which are greater than 2 in 2022. In recent years, TIIs between Zhejiang Province and Brunei, Japan, South Korea, and Singapore were all less than 1, indicating relatively loose bilateral trade relations and a large amount of room for improvement.

Table 2. TIIs between Zhejiang Province and RCEP countries, 2012-2022

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Japan	1.175	1.188	1.085	1.095	1.126	1.107	1.047	1.015	1.053	0.943	0.874
South Korea	0.868	0.855	0.857	0.954	1.080	0.972	0.963	1.014	1.097	0.969	0.917
Australia	1.506	1.570	1.576	1.643	1.654	1.572	1.737	1.723	1.824	1.770	1.815
New Zealand	1.252	1.271	1.197	1.265	1.294	1.263	1.304	1.263	1.268	1.278	1.385
Brunei Darussalam	1.172	0.640	0.588	0.664	0.693	0.849	2.165	0.690	0.540	0.361	0.413
Cambodia	3.071	4.532	4.739	3.807	4.238	4.230	4.380	4.167	3.817	3.403	4.227
Indonesia	1.578	1.676	1.691	1.770	2.037	2.082	2.147	2.583	2.364	2.481	2.703
Lao PDR	0.545	0.596	0.395	0.327	0.327	0.956	0.921	0.535	0.842	0.607	1.229
Malaysia	1.285	1.429	1.210	1.218	1.272	1.181	1.127	1.276	1.501	1.409	1.309
Philippines	2.326	2.449	2.662	2.528	2.482	2.104	2.024	2.336	2.770	2.667	3.152
Singapore	0.419	0.458	0.398	0.510	0.375	0.304	0.322	0.403	0.551	0.470	0.577
Thailand	1.083	1.005	1.067	1.147	1.260	1.134	1.196	1.380	1.738	1.752	1.765
Myanmar	3.974	3.812	2.944	2.639	3.100	2.288	2.825	3.767	3.509	3.508	5.502
Viet Nam	2.267	2.685	2.412	1.823	1.847	1.769	1.880	2.038	1.888	1.809	2.004

Note: The values were calculated based on the data obtained from World Trade Organization (WTO) database.

It is noteworthy that the TIIs of most countries have been increasing over time, indicating that the trade cooperation and relations between Zhejiang Province and RCEP countries have been strengthened. However, the TIIs of Brunei, Japan, and South Korea showed a decreasing trend, indicating that the bilateral trade did not reach the expected market share due to international political and economic factors. In the event that the RCEP agreement was signed and entered into force, it will be able to further eliminate trade barriers between partner countries, achieve a greater degree of trade liberalization, and strengthen trade cooperation.

4.3 Level of Digital Economy Development in RCEP Countries

4.3.1 Construction of the Indicator System

The level of digital economy development varies among RCEP countries. Neither at home nor abroad, a unified indicator system has been established for the level of digital economy development. In this study, indicators were selected based on the foundational concept and characteristics of digital economy development presented in the “**Theoretical Analysis**” section. The carrier of digital economy is the infrastructure based on modern information network. The output of digital economy is the added value created by promoting the efficiency of traditional economies and advancing industrial development, which is fueled by innovation in digital technologies. Therefore, three elements of digital infrastructure, industrial development and technological innovation were chosen as the first-level indicators of the evaluation system of the level of digital economy development of RCEP countries. In the selection of secondary indicators, this paper drew on the research findings on digital economy and related subjects of domestic and foreign scholars and research institutions, and incorporated the actual situation of the RCEP countries. By adhering the principles of objectivity, scientificity and comparability, the following indicator system was finally constructed, as shown in Table 3.

Table 3. Indicator system for the level of digital economy development in RCEP countries.

Target layer	Criterion layer (Weight)	Indicator layer (Weight)	Symbol	Indicator measurement method	Indicator attribute
Digital economy	Digital infrastructure (0.2259)	Fixed broadband penetration (0.2071)	X_1	Fixed broadband subscriptions (per 100 people)	+
		Mobile cellular penetration (0.0188)	X_2	Mobile cellular subscriptions (per 100 people)	+
	Industrial development (0.3685)	Economic environment (0.3047)	X_3	GDP per capita (current US\$)	+
		Contribution of tertiary industry (0.0638)	X_4	Services, value added (% of GDP)	+
	Technological innovation (0.4056)	High-tech competitiveness (0.1414)	X_5	High-technology exports (% of manufactured exports)	+
		ICT product competitiveness (0.2642)	X_6	ICT goods exports (% of total goods exports)	+

Note: “+” indicates a positive attribute of the indicator.

In this paper, the panel entropy method was used to assign weights to the indicators. Following are the calculation steps.

Suppose the data contains J indicators of I countries over T years, then X_{tij} denotes the indicator j of country i in the year t .

Considering the differences in units and dimensions among various indicators, data must be dimensionless to facilitate comparisons.

$$X'_{tij} = \frac{X_{tij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}} \tag{2}$$

Where $\max\{X_j\}$ and $\min\{X_j\}$ represent the maximum value and minimum value of indicator j , respectively, and X'_{tij} denotes the standardized form of indicator X_{tij} .

As data standardization will produce 0 value, it is necessary to shift the standardization data to eliminate this bias.

$$X''_{tij} = X'_{tij} + H \tag{3}$$

Where H is the shift magnitude of the indicators, which is chosen to be 0.0001 in this study.

Normalization of indicators:

$$Y_{tij} = \frac{X''_{tij}}{\sum_t \sum_i X''_{tij}} \tag{4}$$

$$e_j = -k \sum_t \sum_i (Y_{tij} \times \ln Y_{tij}), k = \frac{1}{\ln T \times I} \tag{5}$$

$$d_j = 1 - e_j \quad (6)$$

In formula (5), e_j represents the information entropy, d_j represents information entropy redundancy, $T = 11$ denotes 11 years in the research period, and $I = 15$ denotes 15 RCEP countries.

$$W_j = \frac{d_j}{\sum_j d_j} \quad (7)$$

Where W_j denotes the weight of each indicator.

$$U_{ti} = \sum_j W_j \times X'_{tij} \quad (8)$$

In formula (8), U_{ti} represents the comprehensive score of digital economy of the country i in the year t .

This study examined the level of digital economy development of 15 RCEP countries from 2012 to 2022, considering the fact that the agreement was initiated by the ASEAN in 2012 and took effect on 1 January 2022, as well as the availability of data on relevant indicators. These countries included China, Japan, South Korea, Australia, New Zealand, Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, the Philippines, Singapore, Thailand, Myanmar and Viet Nam. The original research data was primarily gathered from the World Development Indicators (WDI) database of World Bank.

4.3.2 Analysis of Digital Economy Development

Table 4 illustrates the comprehensive values of the levels of digital economy development for RCEP countries after calculation.

Table 4. Comprehensive values of digital economies of RCEP countries, 2012-2022.

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
China	0.317	0.330	0.326	0.361	0.378	0.408	0.421	0.431	0.447	0.459	0.461
Japan	0.468	0.437	0.430	0.421	0.440	0.441	0.447	0.454	0.467	0.464	0.440
South Korea	0.457	0.481	0.496	0.512	0.520	0.550	0.583	0.565	0.592	0.613	0.578
Australia	0.470	0.477	0.467	0.455	0.440	0.455	0.474	0.476	0.468	0.499	0.519
New Zealand	0.369	0.382	0.396	0.378	0.391	0.400	0.406	0.404	0.405	0.436	0.439
Brunei Darussalam	0.235	0.241	0.219	0.216	0.201	0.240	0.192	0.212	0.205	0.225	0.247
Cambodia	0.029	0.040	0.036	0.048	0.047	0.045	0.046	0.044	0.047	0.051	0.064
Indonesia	0.088	0.086	0.086	0.088	0.090	0.094	0.092	0.098	0.102	0.098	0.099
Lao PDR	0.045	0.053	0.123	0.158	0.155	0.152	0.153	0.110	0.110	0.067	0.071
Malaysia	0.370	0.376	0.383	0.385	0.383	0.388	0.408	0.407	0.426	0.413	0.374
Philippines	0.334	0.327	0.372	0.421	0.427	0.393	0.411	0.484	0.508	0.497	0.506
Singapore	0.647	0.668	0.668	0.677	0.693	0.695	0.700	0.698	0.711	0.775	0.789
Thailand	0.225	0.228	0.235	0.248	0.255	0.268	0.273	0.276	0.298	0.296	0.294
Myanmar	0.016	0.017	0.022	0.025	0.052	0.041	0.045	0.048	0.049	0.052	0.046
Viet Nam	0.212	0.261	0.262	0.307	0.328	0.358	0.368	0.382	0.412	0.434	0.451

According to the data presented in Table 4, the digital economy has developed steadily between 2012 and 2022 on an overall upward trend. However, there were significant differences among RCEP countries. Singapore, South Korea, and Australia ranked top three in terms of digital economy level in 2022. These three countries also ranked highly in the digital infrastructure index, which illustrates that digital infrastructure construction and investment in IT industry are essential to the digital economy development of a country. It is observed that Singapore led the RCEP countries in digital economy, especially in terms of its industrial development index, indicating that the synthesis of emerging technologies with traditional industries is the key driver for the digital economy development and its inclusive growth.

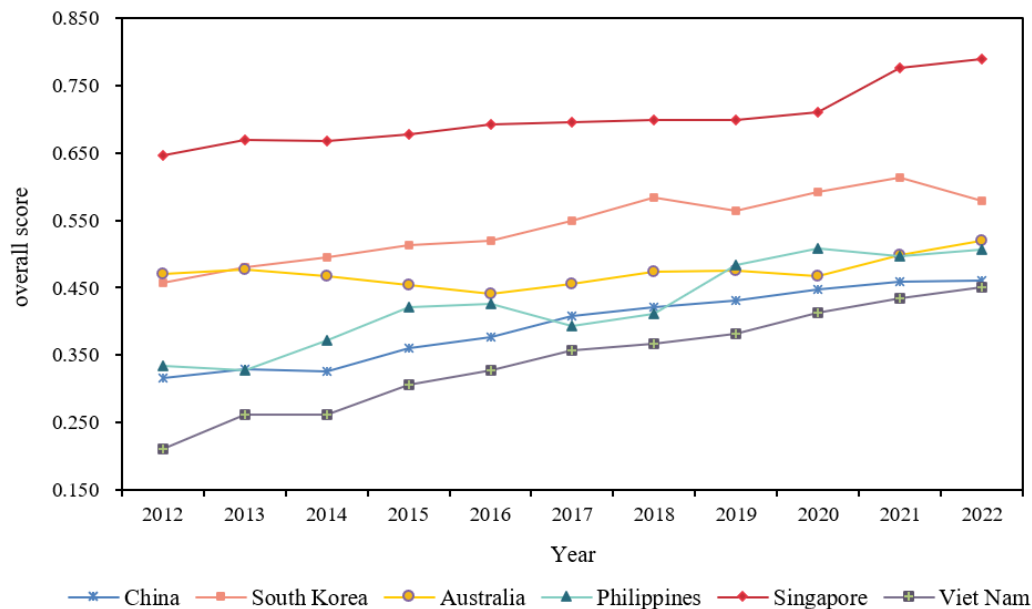


Figure 3. Top 6 RCEP countries in terms of overall score for the level of digital economy

As shown in Figure 3, the Philippines and Viet Nam entered the top six RCEP countries in terms of digital economy due to their competitive advantages in technological innovation, with considerable potential for development. However, there was a generally low level of external competitiveness of digital technology in other countries, indicating problems such as mismatches between input and output and continued delays in transformations of technological innovation achievements. It is noteworthy that Myanmar, ranked at the bottom, scored less than one tenth of Singapore, demonstrating a serious regional imbalance in the level of digital economy development in RCEP countries and the existence of a profound "digital divide". In this article, the main concern is whether and how the level of digital economy development in RCEP countries affects the trade efficiency of the exporting region.

5. Research Design

5.1 Research Method

5.1.1 SFGM

The stochastic frontier production function was first applied by Aigner et al. [74] to test the technical efficiency of production and the maximized production under given conditions. In the SFGM, the trade potential between two countries can be viewed as the maximum volume of trade given the size of economies, distance and other factors. The specific form of the SFGM set up in this paper is as follows:

$$T_{ijt} = f(x_{ijt}, \beta) \exp(v_{ijt} - \mu_{ijt}) \tag{9}$$

$$\ln T_{ijt} = \ln f(x_{ijt}, \beta) + v_{ijt} - \mu_{ijt} \tag{10}$$

$$T_{ijt}^* = f(x_{ijt}, \beta) \exp(v_{ijt}) \tag{11}$$

$$TE_{ijt} = \frac{T_{ijt}}{T_{ijt}^*} = \exp(-\mu_{ijt}), \mu_{ijt} \geq 0, TE_{ijt} \in [0,1] \tag{12}$$

Where equation (10) is the logarithmic form of equation (9), T_{ijt} represents the actual trade volume between country i and country j in period t , and T_{ijt}^* represents the maximum trade volume that can be reached between country i and country j under the given natural resource endowment, i.e., the trade potential. x_{ijt} denotes the main natural factors affecting trade volume between the two countries, including the size of the two economies, distance, etc., and β is the coefficient of the corresponding explanatory variable. $v_{ijt} - \mu_{ijt}$ is the composite error term. v_{ijt} and μ_{ijt} are independent of each other. v_{ijt} denotes the random error term, which represents the unobservable factors affecting the trade volume, and obeys a normal distribution, i.e. $v_{ijt} \sim N(0, \sigma_v^2)$. μ_{ijt} denotes the trade inefficiency term, including the human factors affecting the trade volume between the two countries, which may be artificially altered within a short period of time, and usually obeys a semi-normal, truncated normal or exponential distribution. In equation (12), TE_{ijt} is the ratio of actual trade volume to trade

potential, i.e. the trade efficiency between the two countries. When $\mu_{ijt} = 0$, then $TE_{ijt} = 1$, the actual trade volume is equal to the maximum trade volume, and the trade between the two countries is in an optimal state. When $\mu_{ijt} > 0$, there is trade inefficiency. At this time, $0 < TE_{ijt} < 1$, the actual trade volume is less than the maximum trade volume, suggesting there is room for trade expansion. In light of the fact that the trade inefficiency term may vary over time, the time-varying decay model (TVDM) proposed by Battese and Coelli [75] can provide estimates of the time-varying technical efficiency of each sample. The specific form of the model is as follows:

$$\mu_{ijt} = \{exp[-\eta(t - T)]\}\mu_{ij}, t \in T(i) \quad (13)$$

Where η is the coefficient to be estimated and μ_{ijt} obeys a truncated normal distribution. When $\eta = 0$, the trade inefficiency term remains constant over time, resulting in the time-invariant model (TIM). When $\eta > 0$, the trade inefficiency term decreases over time, indicating a reduction in the overall negative impact. When $\eta < 0$, the trade inefficiency term increases over time, indicating an increase in the overall negative impact on trade.

5.1.2 Trade Inefficiency Model

The trade inefficiency model was established in this paper in order to further analyze the factors affecting trade efficiency. This paper adopted the "one-step method" proposed by Battese and Coelli [76] to avoid the contradiction of independent and identically distributed hypotheses of trade inefficiency term in the "two-step method". The basic form of the model is as follows:

$$\mu_{ijt} = \delta z_{ijt} + \omega_{ijt} \quad (14)$$

In equation (14), z_{ijt} denotes the exogenous variable affecting trade efficiency, and δ is the coefficient to be estimated. If $\delta > 0$, then z_{ijt} has a positive impact on trade inefficiency, i.e., it affects trade efficiency negatively. If $\delta < 0$, then z_{ijt} affects trade efficiency positively. ω_{ijt} is the random error term that follows a normal distribution. The following formula is obtained by substituting equation (14) into equation (10).

$$\ln T_{ijt} = \ln f(x_{ijt}, \beta) + v_{ijt} - (\delta z_{ijt} + \omega_{ijt}) \quad (15)$$

5.2 Model Setting and Variable Description

Drawing on the methodology proposed by Armstrong [47], this paper selected population, contiguity, and common language as the natural factors affecting trade flow, along with the two original variables of economic size and geographical distance in the traditional gravity model. The model expression is as follows.

$$\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln Dist_{ij} + \beta_6 Contig_{ij} + \beta_7 Comlang_{ij} + v_{ijt} - \mu_{ijt} \quad (16)$$

Where i represents Zhejiang Province, j denotes other RCEP countries, t donates time. The dependent variable EXP_{ijt} is the actual export volume from Zhejiang Province to RCEP country j in time t . Following is a description of the independent variables. GDP_{it} and GDP_{jt} represent the economic scale of Zhejiang Province and RCEP country j in period t , reflecting the level of economic development and supply and demand in these regions. In general, they are positively correlated with EXP_{ijt} . $Dist_{ij}$ denotes the geographical straight-line distance between provincial capital of Zhejiang Province and capital of RCEP country j , reflecting the cost of transportation between the two regions. It is generally expected to be negatively correlated with EXP_{ijt} . POP_{it} and POP_{jt} represent the population of Zhejiang Province and RCEP country j in period t , respectively. They reflect the market size of the two regions, which are usually expected to be positively correlated with EXP_{ijt} . $Contig_{ij}$ and $Comlang_{ij}$ are dummy variables. $Contig_{ij}$ represents the contiguity of the two regions. A value of 1 indicates that the two regions share a border, while a value of 0 indicates that they do not share a border. $Comlang_{ij}$ represents whether the two regions have a common official language, 1 for yes and 0 otherwise.

Moreover, this study established the trade inefficiency model to analyze the factors affecting export efficiency of Zhejiang Province to RCEP countries based on their trade characteristics. Aside from focusing on the level of digital economy development, the model also incorporated the factors of regional integration, economic freedom, and trade facilitation. The specific form of the model is as follows.

$$\mu_{ijt} = \delta_0 + \delta_1 DIG_{jt} + \delta_2 FTA_{ijt} + \delta_3 TRA_{jt} + \delta_4 GOV_{jt} + \delta_5 SHP_{jt} + \omega_{ijt} \quad (17)$$

Where DIG_{jt} represents the level of digital economy development in RCEP country j in period t , which is the core variable to be examined in this paper. FTA_{ijt} represents the signing of FTAs between China and RCEP country j in period t , which indicates the degree of regional integration. It is a dummy variable that takes the value of 1 when it is signed and comes into effect, and 0 otherwise. TRA_{jt} and GOV_{jt} represent the degree of trade freedom and the index of government effectiveness in RCEP country j in period t , reflecting the economic

and institutional environment of the importing country. SHP_{jt} represents the liner shipping connectivity index of RCEP country j in period t , indicating the degree of trade facilitation in the importing country.

5.3 Sample Selection and Data Source

Considering the availability of data, this paper selected Zhejiang Province of China and the remaining 14 RCEP countries as the research object and the panel data from 2012 to 2022, with 154 valid observations in total.

In the SFGM, the export values of Zhejiang Province to RCEP countries were obtained from the China Customs Statistics Database, the data on GDP (current US\$) and population of RCEP countries was obtained from the World Development Indicators (WDI) database of the World Bank, and the data on Gross Regional Product and population of Zhejiang Province was collected from the China Statistical Yearbook. The geographical distances refer to the straight-line distances between Hangzhou, the provincial capital of Zhejiang Province, and the capital cities of RCEP countries, which were measured by Google maps. Data on contiguity and common official language was provided by the CEPII database.

In the trade inefficiency model, the values of digital economy of RCEP countries were measured in Section 4.3 Level of Digital Economy Development in RCEP Countries. The FTAs information was derived from China Free Trade Zone Service Network. The trade freedom degrees were collected from the Heritage Foundation, and the government effectiveness indexes were obtained from the Worldwide Governance Indicators (WGI) database. The liner shipping connectivity indexes were available from the United Nations Conference on Trade and Development (UNCTAD) database. Table 5 shows descriptive statistics of each variable.

Table 5. Descriptive statistics of each variable.

Variable	Observation	Mean	Std. dev.	Min	Max
$\ln EXP_{it}$	154	21.409	1.741	16.898	23.483
$\ln GDP_{it}$	154	27.404	0.227	27.068	27.774
$\ln GDP_{jt}$	154	26.244	1.740	23.045	29.467
$\ln POP_{it}$	154	8.726	0.048	8.646	8.791
$\ln POP_{jt}$	154	17.071	1.644	12.916	19.434
$\ln Dist_{ij}$	154	7.506	0.572	6.457	8.708
$Contig_{ij}$	154	0.214	0.412	0	1
$Comlang_{ij}$	154	0.143	0.351	0	1

6. Empirical Results and Discussions

On the panel data of export from Zhejiang Province to RCEP countries from 2012 to 2022, this paper estimated the time-varying SFGM and the trade inefficiency model with Frontier version 4.1.

6.1 Applicability Test

To ensure the rationality and rigor of the SFGM, the likelihood ratio test was adopted to test its applicability. Four main tests were set in this paper: whether the trade inefficiency term exists, whether this term changes over time, whether the variable of contiguity is introduced in the model, and whether the variable of common official language is introduced. In the SFGM, the weight of human factors in the composite error term can be described by the variance parameter. The specific form is as follows.

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \quad (18)$$

$$\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2} \quad (19)$$

Where the value of γ represents the weight of the trade inefficiency term in the composite error term. When γ approaches 0, it indicates that the composite error term mainly originates from the unobservable random error term. When $\gamma = 0$, the trade inefficiency term does not exist, i.e. $\mu_{ijt} = 0$, and the model can be estimated by ordinary least squares (OLS). If γ is closer to 1, it means that the gap between the actual trade volume and the frontier trade volume mainly comes from the trade inefficiency term. As shown in Table 6, the original hypotheses and the results of applicability test of the model are presented.

Table 6. Applicability test of SFGM

Null hypothesis	Log likelihood of constrained model	Log likelihood of unconstrained model	LR test value	1% threshold	Test conclusion
$\mu_{ijt} = 0$	-132.094	-1.259	261.670	14.325	refuse
$\eta = 0$	-1.259	7.512	17.542	12.483	refuse
$Contig_{ij}$ is not introduced	7.197	7.512	0.630	10.501	accept
$Comlang_{ij}$ is not introduced	6.366	7.512	2.292	10.501	accept

Note: the values were output by Frontier 4.1. $LR\ statistics = -2 \times (\ln H_0 - \ln H_1)$, LR has a mixed chi-square distribution.

It is verified in Table 6 that the SFGM can be used to measure the export efficiency of Zhejiang Province to RCEP countries as the null hypothesis that trade inefficiency does not exist was rejected. As the null hypothesis that trade inefficiency is constant was also rejected, it is fair to use the time-varying SFGM. In addition, the tests accepted the hypotheses that $Contig_{ij}$ and $Comlang_{ij}$ are not introduced. Therefore, the model used in this paper is modified as follows.

$$\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln Dist_{ij} + v_{ijt} - \mu_{ijt} \quad (20)$$

6.2 Analysis of Regression Results of SFGM

This paper estimated the SFGM based on the panel data of export of Zhejiang Province to RCEP countries from 2012 to 2022 after the applicability test. To ensure the robustness and accuracy of the results, OLS, TIM, and TVDM were used to estimate the regression results, respectively, and the results are shown in Table 7. It can be observed that the regression coefficients of the variables in three models are basically uniform, suggesting the robustness of the regression results. Additionally, the values of γ in the TIM and TVDM are 0.990 and 0.988, respectively, and both are significant at the 1% significance level. This indicates that 99.0% and 98.8% of the variance in the composite error term is attributed to the trade inefficiency term, i.e., human factors are primarily responsible for the gap between the actual export volume of Zhejiang Province to RCEP countries and its trade potential. In the TVDM, η passes the significance test at the 1% level, indicating that the trade inefficiency term varies over time. Again, this confirms the rationality of applying the time-varying SFGM. The positive coefficient of η indicates that the trade efficiency between Zhejiang Province and RCEP countries was increasing, as well as the trade resistance was decreasing over time.

Table 7. Regression results of OLS, TIM and TVDM.

Estimation model	OLS		TIM		TVDM	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	-21.189	-1.091	-15.405**	-2.513	-3.779	-0.686
$\ln GDP_{it}$	1.889	1.509	1.951***	5.388	1.949***	5.946
$\ln GDP_{jt}$	0.638***	15.365	0.480***	11.001	0.440***	8.112
$\ln POP_{it}$	-3.756	-0.630	-3.704**	-2.111	-4.994***	-3.258
$\ln POP_{jt}$	0.380***	8.253	0.326***	4.474	0.349***	6.290
$\ln Dist_{ij}$	0.050	0.494	-0.235	-1.242	-0.188	-1.310
σ^2	0.431	/	4.057	1.454	3.048	1.578
γ	/	/	0.990***	135.668	0.988***	115.265
η	/	/	/	/	0.028***	5.385
Log likelihood	-150.718		-1.703		6.159	
LR test value	/		298.030		313.753	

Note: *, **, ***, represent being significant at 10%, 5% and 1% significance levels respectively.

According to the output of TVDM in Table 7, the coefficients of $\ln GDP_{it}$ and $\ln GDP_{jt}$ are both significantly positive at the 1% significance level. This indicates that the expansion of economic scale of Zhejiang Province and the RCEP countries would boost exports from the former to the latter. $\ln POP_{jt}$ demonstrated significantly

positive elasticity at the 1% significance level, indicating that an increase in the population size of RCEP countries would lead to an expansion in market demand, which positively affected export trade of Zhejiang Province. However, the effect of population size in Zhejiang Province ($\ln POP_{it}$) was significantly negative. This is probably due to the fact that as the population grows in the export region, it stimulates domestic demand and consumes a portion of the exported goods, thereby hindering export to other countries. The coefficient of variable $\ln Dist_{ij}$ is negative, but it does not pass the significance test, indicating that the distance between the two sides of the trade has little impact on export trade. With the construction of trade and transport-related infrastructure and the increase in international air routes, which makes regional trade facilitation effectively improved, resulting in a significant reduction in transport time and trade costs. Therefore, the effect of geographical distance on export trade has been weakened to a certain extent.

6.3 Analysis of Regression Results of Trade Inefficiency Model

6.3.1 Using Digital Economy as the Core Variable

According to the results of the likelihood ratio test, it was known that trade inefficiency exists and changes over time. This paper employed the "one-step method" to estimate the trade inefficiency model, with digital economy as the key explanatory variable. The results are shown in Table 8.

Table 8. Regression results of Trade Inefficiency Model with digital economy as core variable.

SFGM			Trade Inefficiency Model		
Variable	Coefficient	t-ratio	Variable	Coefficient	t-ratio
Constant	-10.175**	-2.205	Constant	4.824***	4.645
$\ln GDP_{it}$	1.789***	5.667	DIG_{jt}	-2.676***	-2.624
$\ln GDP_{jt}$	0.263***	14.119	FTA_{ijt}	0.542*	1.749
$\ln POP_{it}$	-3.355**	-2.345	TRA_{jt}	-0.036***	-2.638
$\ln POP_{jt}$	0.329***	11.929	GOV_{jt}	0.590***	3.492
$\ln Dist_{ij}$	0.018	0.548	SHP_{jt}	-0.016***	-5.591
			σ^2	0.929***	6.636
			γ	0.989***	191.864
Log likelihood	-61.772				
LR test value	177.891				

Note: *, **, ***, represent being significant at 10%, 5% and 1% significance levels respectively.

In the SFGM, the coefficients of $\ln GDP_{it}$, $\ln GDP_{jt}$ and $\ln POP_{jt}$ are significantly positive at the 1% significance level. Among them, $\ln GDP_{it}$ has the largest elastic parameter of 1.789, implying that the economic size of Zhejiang Province is the largest contributor to export volume. In addition, the economic size and population size of Zhejiang Province have a greater impact on export trade than those of importing nations.

In the trade inefficiency model, variables DIG_{jt} , TRA_{jt} and SHP_{jt} have significant negative coefficients at the 1% significance level. This implies that these variables have a negative relationship with trade inefficiency, i.e. positively related to export efficiency. Among these variables, the core variable DIG_{jt} has the largest elasticity parameter (-2.676), which implies that the improvement in digital economy in RCEP countries has the largest promotion impact on the export efficiency of Zhejiang Province. This is reasonable. Firstly, ICT and other digital technologies facilitate the efficient transmission of information, thus reducing transaction costs for both sides of trade, including information costs, communication costs, and other costs. Secondly, digital economy development in importing countries is conducive to improving the efficiency of the flow of factor information, reducing the mismatch of resources brought about by information asymmetry, thus optimizing export efficiency. Finally, in the era of digital economy, high-speed and efficient cross-border e-payment platforms assist in the acceleration of economic and trade exchanges and cooperation within the RCEP region. The coefficients of variables TRA_{jt} and SHP_{jt} are relatively small, suggesting that trade freedom and liner shipping do not promote export efficiency as much as digital economy.

Additionally, variable GOV_{jt} is positively correlated with trade inefficiency at the 1% significance level, suggesting that the effectiveness of government in RCEP countries hinders trade efficiency to some degree. A possible explanation for this is that when government effectiveness is low, regulations are weak, and enterprises in the importing country may expand their trade flow through rent-seeking activities. However, when government effectiveness is improved, regulations are more stringent and rent-seeking behavior cannot be conducted, which

impedes trade flow to some extent. It is noteworthy that the coefficient of FTA_{ijt} is significant at the 10% significance level, but it is positively associated with trade inefficiency. This implies that FTA hinders trade efficiency, which is contrary to expectations. The results of previous studies showed that FTAs in force between trading countries can effectively reduce trade barriers and frictions, as well as reduce trade efficiency losses. However, since the research object is RCEP countries, the benefits of FTAs related to China in promoting export efficiency were not realized due to the exclusiveness and trade diversion effects of the TPP.

6.3.2 Using Different Dimensions of Digital Economy as Core Variables

In order to further study the impact of digital economy development on export efficiency, this study introduced three first-level indicators measuring digital economy development into the SFGM respectively. Specifically, it examined the degree of impact of digital infrastructure (DI), industrial development (ID) and technological innovation (TI) of RCEP countries on the export efficiency of Zhejiang Province, which are expressed as Model 1, Model 2, and Model 3, respectively. The formulas are as follows. The regression results are presented in Table 9.

$$\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln Dist_{ij} + v_{ijt} - (\delta_0 + \delta_1 DI_{jt} + \delta_2 FTA_{ijt} + \delta_3 TRA_{jt} + \delta_4 GOV_{jt} + \delta_5 SHP_{jt} + \omega_{ijt}) \quad (21)$$

$$\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln Dist_{ij} + v_{ijt} - (\delta_0 + \delta_1 ID_{jt} + \delta_2 FTA_{ijt} + \delta_3 TRA_{jt} + \delta_4 GOV_{jt} + \delta_5 SHP_{jt} + \omega_{ijt}) \quad (22)$$

$$\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln Dist_{ij} + v_{ijt} - (\delta_0 + \delta_1 TI_{jt} + \delta_2 FTA_{ijt} + \delta_3 TRA_{jt} + \delta_4 GOV_{jt} + \delta_5 SHP_{jt} + \omega_{ijt}) \quad (23)$$

Table 9. Regression results of trade inefficiency model with different dimensions of digital economy as core variables

Variable	Model 1		Model 2		Model 3	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant β_0	1.599	0.336	2.322	0.387	-12.067***	-3.362
$\ln GDP_{it}$	2.356***	7.695	2.479***	6.316	1.654***	5.806
$\ln GDP_{jt}$	0.235***	12.190	0.248***	12.242	0.270***	13.599
$\ln POP_{it}$	-6.434***	-4.528	-6.911***	-3.703	-2.704**	-2.211
$\ln POP_{jt}$	0.347***	16.567	0.334***	14.147	0.314***	11.387
$\ln Dist_{ij}$	0.025	0.887	0.013	0.433	0.016	0.467
Constant δ_0	5.181***	4.925	4.485***	3.854	3.846***	3.583
DI_{jt}	-16.080***	-4.740	\	\	\	\
ID_{jt}	\	\	-5.002**	-2.273	\	\
TI_{jt}	\	\	\	\	1.336	1.230
FTA_{ijt}	-0.134	-0.391	0.408	1.143	0.588*	1.887
TRA_{jt}	-0.028**	-2.260	-0.029*	-1.913	-0.028**	-2.046
GOV_{jt}	0.827***	4.809	0.629***	3.466	0.320**	2.175
SHP_{jt}	-0.012***	-10.865	-0.015***	-9.268	-0.018***	-5.574
σ^2	0.596***	5.769	0.722***	5.338	0.898***	6.143
γ	0.988***	233.783	0.988***	217.684	0.988***	136.380
Log likelihood	-53.348		-58.364		-62.568	
LR test value	194.739		184.708		176.300	

Note: *, **, *** represent being significant at 10%, 5% and 1% significance levels respectively

Table 8 and Table 9 show that the sign of the explanatory variables in each model is basically uniform, suggesting that the model is robust. In Model 1, the variable DI_{jt} passes the significance test at 1% level. This indicates that the construction and improvement of digital infrastructure can reduce the transaction cost of export trade, shorten the transaction cycle, reduce the risk and uncertainty in trade, and can effectively enhance trade efficiency. Hypothesis 1 proposed in the ‘‘Theoretical Analysis’’ section is verified.

In model 2, the variable ID_{jt} is significantly negative at the 5% significance level, which indicates that industrial digitalization in RCEP countries contributed to export efficiency of Zhejiang Province. The synthesis of digital economy and traditional industries in importing countries can promote the optimization and upgrading of their

domestic industrial structure, which can, to a certain extent, increase the demand for imports of related goods and services, thereby increasing market size for the exporting region. The digital platform and digital service system bring convenience to both sides of the trade and improve export efficiency. Hypothesis 2 proposed in the “Theoretical Analysis” section is verified.

In model 3, the variable TI_{jt} fails the significance test and the coefficient is positive. This means that technological innovation in RCEP countries had a slight inhibitory effect on export efficiency of Zhejiang Province, but the effect is not evident. Possibly, the greater capacity of digital technological innovation of a country, the more competitive its export products will be and, to a certain extent, this will inhibit the export competitiveness and export efficiency of other countries.

6.4 Robustness Tests

6.4.1 Regression with Different Time Intervals

In order to test whether the effect of digital economy of importing countries on the export efficiency of Zhejiang Province in different time intervals is robust, the sample was divided into three sub-samples with different time intervals, and separate regression analyses were conducted. The results are presented in Table 10 in columns (1)-(3). Among them, column (1) refers to 2012-2018 with a 7-year interval, and column (2) refers to 2014-2021 with an 8-year interval. Column (3) examines robustness over the most recent 6-year period, from 2017 to 2022.

6.4.2 Regression with Alternative Indicator

In addition, since there are different indicator weight measures for measuring the level of digital economy development, principal component analysis was conducted to re-measure digital economy in RCEP countries in order to verify the robustness of these results. The results are presented in column (4) of Table 10.

Table 10. Regression results of six trade inefficiency model

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Constant	9.040*** (7.483)	5.364*** (4.390)	1.579 (1.547)	4.619*** (3.820)	0.380 (0.544)	1.655 (1.043)
DIG_{jt}	-3.520* (-1.677)	-2.415** (-2.170)	-2.334** (-2.254)	-0.457*** (-2.648)	-7.480*** (-6.583)	8.698*** (4.505)
FTA_{ijt}	0.865*** (3.140)	0.193 (0.669)	-0.348 (-0.878)	0.445 (1.340)	0.353*** (6.644)	4.027*** (4.949)
TRA_{jt}	-0.095*** (-5.983)	-0.038** (-2.317)	0.016 (1.217)	-0.042*** (-2.881)	0.027* (1.870)	-0.063** (-2.435)
GOV_{jt}	1.186*** (5.582)	0.548** (2.513)	0.098 (0.506)	0.573*** (3.553)	0.278 (0.820)	0.484 (1.328)
SHP_{jt}	-0.009*** (-10.635)	-0.016*** (-4.233)	-0.012*** (-3.917)	-0.016*** (-5.871)	0.001 (1.308)	-0.026*** (10.520)
σ^2	0.467*** (9.334)	0.970*** (4.477)	0.537*** (5.828)	0.931*** (7.448)	0.205*** (5.949)	0.975*** (3.897)
γ	1.000*** (313.539)	0.994*** (234.408)	0.968*** (56.185)	0.990*** (160.646)	1.000*** (144496.850)	0.999*** (717.591)
Log likelihood	-23.772	-44.707	-31.699	-60.600	-0.508	-11.788
LR test value	145.544	129.331	89.134	180.236	47.395	175.819

Note: *, **, *** represent being significant at 10%, 5% and 1% significance levels respectively, with t-values in brackets.

It can be seen from Table 10 that the coefficient of the core variable DIG_{jt} is always significantly negative after the test of different time intervals and alternative variable. This suggests that the results of the impact of digital economy of RCEP countries on the export efficiency of Zhejiang Province are robust.

6.5 Heterogeneity Test

Further, regression analyses were conducted to determine how digital economy of RCEP countries with different income levels affects the export efficiency of Zhejiang Province. According to the World Bank Group country classification by income level, our analysis classified RCEP countries into high-income countries and middle-

income countries. The results are shown in columns (5) and (6) of Table 10, respectively. The regression results of high-income countries show that the coefficient of the core variable DIG_{jt} is significantly negative, indicating that the improvement of the digital economy level of high-income RCEP countries is significantly promoting the export efficiency of Zhejiang. It may be related to the fact that high-income countries have more developed digital ecosystems, better-optimized industrial structures, and a stronger market consumption capacity. However, according to the regression results of middle-income countries, the coefficient of core variable is significantly positive. This finding is contrary to expectations. An in-depth analysis of the reason for this may suggest that although middle-income RCEP countries are also actively developing digital economy, their development is relatively low, and they may be facing a number of challenges to digital transformation, such as inadequate infrastructure, a shortage of talent, and an imperfect institutional environment. To a certain extent, these factors limit the penetration and competitiveness of export products in these markets. In particular, when rapid development in digital economy and the transformation of traditional economic structures fail to interconnect effectively, it may result in a rise in trade costs and trade uncertainty, which may adversely affect export efficiency of Zhejiang Province.

6.6 Measurement and Analysis of Export Efficiency

In this paper, the export efficiency of Zhejiang Province to RCEP countries from 2012 to 2022 was obtained through the trade inefficiency model based on the "one-step method". As shown by equation (13), when trade inefficiency term significantly exists, then $TE_{ijt} \in [0, 1)$. The closer TE_{ijt} is to 1, the larger the export efficiency is and the closer the actual export volume is to the frontier trade volume. And a smaller TE_{ijt} implies lower export efficiency and a larger trade expandable space. Measurement results show that the average export efficiency of Zhejiang Province to RCEP countries in 2012-2022 is 0.584. There is still much room for improvement, suggesting that RCEP countries are the markets with greater export potential for Zhejiang Province in the future.

6.6.1 Analysis of Export Efficiency by Country

Figure 4 illustrates the average export efficiency of Zhejiang Province to RCEP countries from 2012 to 2022, revealing the highest export efficiency of 0.928 to South Korea, followed by Vietnam and Australia. In addition to the export trade potential between the above countries and Zhejiang Province being fully tapped, the export volume continued to grow rapidly. Furthermore, Zhejiang Province had the lowest export efficiency to Laos and Brunei, primarily due to the insufficient construction of digital infrastructure in these countries, which resulted in higher bilateral trade costs. These two countries also have smaller economic volume and market demand, thereby limiting the export efficiency and trade flow.

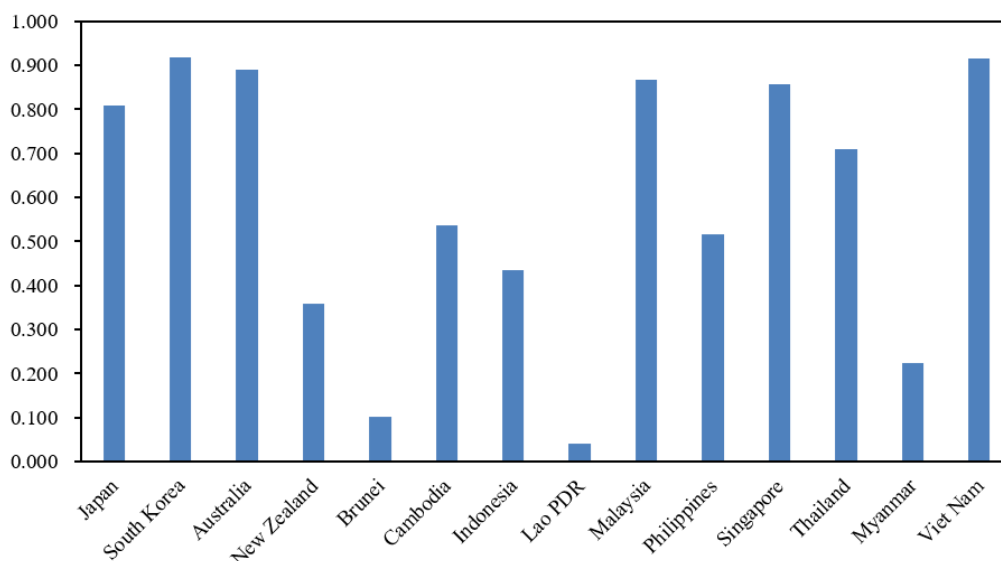


Figure 4. Average value of export efficiency of Zhejiang Province to RCEP countries, 2012-2022

For a more intuitive analysis of the temporal evolution trend and regional distribution characteristics of export efficiency of Zhejiang Province to RCEP countries, representative data for year 2012, 2016, 2019, and 2022 were selected, and the spatial-temporal evolution map was plotted using ArcGIS 10.8, as shown in Figure 5. Referring to existing studies, this paper classified the corresponding markets into four categories based on trade efficiency

values, namely iceberg type ($TE_{ijt} \in [0, 0.3)$), development type ($TE_{ijt} \in [0.3, 0.6)$), expansion type ($TE_{ijt} \in [0.6, 0.9)$), and saturation type ($TE_{ijt} \in [0.9, 1]$) [77].

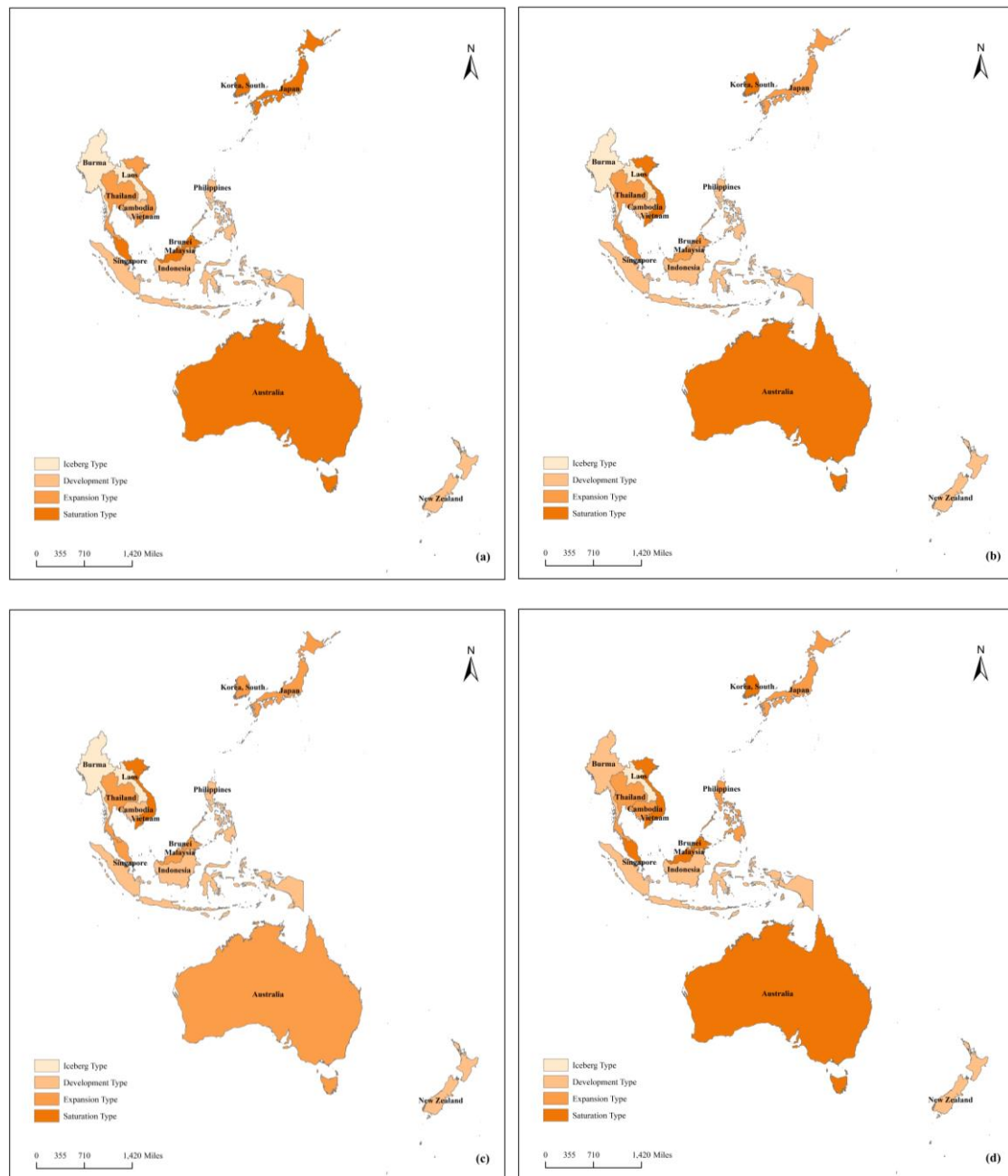


Figure 5. Spatial-Temporal Evolution of export efficiency of Zhejiang Province to RCEP countries in: (a) 2012; (b) 2016; (c) 2019; (d) 2022.

As shown in Figures 4 and 5, only South Korea and Vietnam were of saturation type in terms of average export efficiency. In addition, Australia and Malaysia had some saturation period. However, viewed from time evolution point, there are no markets that remained stable in the saturation type. Cambodia, the Philippines, Myanmar, and Vietnam are the markets that were continually explored during the study period. It is worth noting that the Japanese market dropped from the earlier saturation type to expansion type, largely due to the current structural change from the past vertical division of labor to horizontal division of labor between China and Japan. Combined with the tensor bilateral relations between China and Japan, economic and trade cooperation encountered some challenges as a result. Other than that, the rest of the countries maintained relatively stable market conditions.

From the point of view of spatial distribution, Oceanian and East Asian markets are relatively saturated. These countries are all developed countries with early digital infrastructure development, and digital economy has played a critical role in promoting trade efficiency in the early stage. In addition, the ASEAN market has continued to expand during the study period, as well as its trade potential has been continuously explored.

6.6.2 Analysis of Export Efficiency by Region

Based upon the geographical location, the RCEP countries were divided into three regions, namely, two countries in East Asia (including Japan and South Korea), two countries in Oceania (including Australia and New Zealand) and ten ASEAN countries, to calculate regional average trade efficiency at specific times. The trade potential of each region can be determined according to formula (13). Table 11 shows the results of the calculations.

Table 11. Average value of export efficiency of Zhejiang Province to RCEP countries by region.

Region	Average export efficiency 2012-2022	Export efficiency in 2012	Export efficiency in 2022	Export efficiency increment 2012 to 2022	Trade potential in 2022 (billion \$)
2 countries in East Asia	0.864	0.949	0.803	-15.42%	37.993
2 countries in Oceania	0.623	0.657	0.639	-2.73%	16.518
10 countries in ASEAN	0.520	0.490	0.621	26.76%	90.059

Note: 2 countries in East Asia includes Japan and South Korea. 2 countries in Oceania includes Australia and New Zealand. 10 countries in ASEAN includes Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Myanmar and Vietnam.

Table 11 illustrates that the average export efficiency of Zhejiang Province to the two East Asian countries is the highest during the study period, followed by the two Oceanian countries and the ten ASEAN nations. This is primarily due to the highly interconnected industrial chains of China, Japan and South Korea, as well as the complementary nature of their economies. However, due to political factors in recent years, the export efficiency of Zhejiang Province to the East Asian region declined 15.42% from 2012 to 2022. Generally, the Oceanian markets were more stable. As a result of increasing cooperation between China and ASEAN in infrastructure construction and customs clearance facilitation, there was a significant increase of 26.76% in export efficiency of Zhejiang Province to ASEAN countries from 2012 to 2022. Moreover, the trade potential of the ten ASEAN countries far exceeded that of the four Southeast Asian and Oceanian countries combined, reaching over 90 billion dollars in 2022. Since ASEAN is highly compatible with Zhejiang Province in terms of market demand, cultural background, etc., as well as significant differences in the internal market, it offers diversified export opportunities for Zhejiang Province. Therefore, ASEAN will be a crucial region for Zhejiang Province to explore its market and increase exports in the future.

7. Conclusions and Countermeasures

By constructing the index system of digital economy development and applying the SFGM, this paper systematically evaluated the influence of digital economy of RCEP countries on export efficiency of Zhejiang Province, revealing the important role of digital economy in promoting international trade through multi-dimensional and multi-level empirical analyses. Based on the results of the study, it can be concluded that the improvement in digital economy of RCEP countries significantly contributed to export efficiency of Zhejiang Province, with differences between different dimensions of digital economy. In particular, both the development of digital infrastructure and industrial digitalization contributed to export efficiency of Zhejiang Province, though the pull effect of digital infrastructure is stronger. Additionally, it was observed that the improvement in digital economy in high-income RCEP countries had a more significant role in increasing export efficiency of Zhejiang Province. During the study period, the export efficiency of Zhejiang Province to ASEAN countries increased the most. It is expected that the competitiveness and influence of Zhejiang Province in the ASEAN market will be further enhanced as digital economy in ASEAN countries continues to improve and regional integration deepens.

7.1 Theoretical Implications

This study theoretically contributes to an advanced understanding of the relationship between digital economy and export efficiency, and it has multiple theoretical implications. Firstly, the exploration of the connotation and characteristics of digital economy, along with the construction of a comprehensive indicator system for evaluating its level of development, provides a solid theoretical foundation for understanding and measuring this emerging economic form, as well as an opportunity for academics and practitioners to better understand the nature and growth prospects of digital economy. Secondly, this research analyzed the impact of digital economy of RCEP countries on export efficiency of Zhejiang Province by applying the SFGM, which not only expands the boundaries of the application of the SFGM in the field of international trade, but also offers a novel perspective for understanding how digital economy is reshaping international trade patterns in the context of globalization. Lastly, this study also distinguishes the heterogeneous impacts of various dimensions of digital economy and countries with different income levels, illustrating the complexity and diversity of the impacts of digital economy on export efficiency, as well as providing a more refined theoretical basis for policy formulation.

7.2 Policy Implications

Based on the research findings, following policy recommendations are offered as a reference for Zhejiang Province and other similar regions seeking to enhance export efficiency under the framework of the RCEP agreement.

- (1) Strengthen the RCEP digital economy circle. It is necessary for RCEP countries to focus on the interconnection of digital economy infrastructure, including increasing Internet penetration rates, optimizing the layout of data centers, and promoting the construction of new types of infrastructure such as 5G and IoT, as well as accelerating the integration of digital economy and traditional industries. It is essential for Zhejiang Province to take full advantage of the opportunities offered by the RCEP agreement, deepen cooperation with RCEP countries in areas of free trade, and promote intraregional trade facilitation jointly.
- (2) Adopt different strategies for cooperation and connection. It is advisable for Zhejiang Province to enhance economic and trade exchanges with high-income countries and actively expand market potential, while paying attention to the various challenges faced by middle-income countries in the process of digital transformation. For instance, the promotion of helping measures, such as technology transfer and talent training, will help narrow the digital divide, reduce market friction and trade uncertainty, and facilitate mutually beneficial trade cooperation.
- (3) Focus on the changes and opportunities in the ASEAN market. It is recommended that, given the importance of the ASEAN market in export trade of Zhejiang Province, close attention be paid to the trends in digital economy development and market change in ASEAN countries in order to explore new paths and new modes for in-depth integration of digital economy and real economy. In addition, customized and differentiated product and service solutions should be provided to meet the specific characteristics and demands of the ASEAN internal markets, thus enhancing trade efficiency within the region.

7.3 Limitations and Future Research

Despite the preliminary results obtained in terms of the impacts of digital economy on international trade efficiency in this research, there are still some limitations. First of all, since the data in this study were based primarily on specific time periods and regions, the generalizability of the results may be limited. In future studies, it might be considered to extend the time period and geographic scope to more comprehensively examine the long-term impact of digital economy on international trade efficiency with cross-regional differences. Secondly, digital economy is a rapidly developing field with constantly evolving connotations and boundaries. Although the digital economy indicator system constructed in this study was intended to be comprehensive, it may still miss certain emerging areas or segmented indicators. With the development of digital economy, the indicator system can be continuously updated and improved in order to measure its level more accurately in the future. Finally, this study mainly focused on how digital economy affects export efficiency, while international trade encompasses many aspects, such as import, services trade, etc. A future research may further explore the impact of digital economy on other aspects of international trade to develop more complete theoretical framework and empirical evidence.

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