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**ARTICLE**

# The Impact of RCEP Partner Countries' Digital Trade Levels on China's Agricultural Exports

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## ABSTRACT

With the development of digital technology, digital economy is gradually becoming a new engine of economic growth, especially in trade, the core area of resource allocation, the impact of digital transformation is particularly significant. In recent years, the scale of China's agricultural export trade has continued to rise, fully demonstrating its potential and vitality. Based on the panel data of agricultural trade volume between China and RCEP partner countries from 2005 to 2022, this paper empirically analyzes the impact of digital trade development level on China's agricultural exports by using stochastic frontier gravity model. The study found that RCEP partner countries' comprehensive infrastructure construction, digital security, international competitiveness of core digital industries, and digital innovation capabilities contribute to the growth of China's agricultural exports. The growth of GDP between China and RCEP partner countries, the signing of free trade agreements, and the improvement of trade openness can promote China's agricultural exports to RCEP partner countries. The greater the geographical distance between China and RCEP member states, the higher tariffs imposed by RCEP member states on agricultural products will increase the cost of China's agricultural exports, and the more unfavorable it will be to China's agricultural exports to RCEP member states.

***Keywords:*** RCEP Partner Countries; Digital Trade; Agricultural Exports; Trade Efficiency; Free Trade Agreements

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# 1. Introduction

The concept of building a China-ASEAN community of shared destiny was introduced by Chinese President Xi Jinping in a key address to the Indonesian parliament in 2013 [1]. Following years of strengthened regional cooperation, the Regional Comprehensive Economic Partnership Agreement (RCEP) came into effect on January 1, 2022. The agreement, which includes the ten ASEAN nations and 15 other countries—China, Japan, South Korea, Australia, and New Zealand—represents 47.4% of the global population, 29.1% of global trade, and 32.2% of global GDP. This makes it the largest economic cooperation framework in the Asia-Pacific, significantly advancing regional economic integration and supporting the multilateral trading system. As the largest agricultural trade hub worldwide, RCEP includes numerous key agricultural producers, consumers, and trading nations [2]. Through mechanisms like tariff reductions and trade facilitation, the agreement has strengthened the resilience of regional agricultural supply chains. Particularly amidst the global food security challenges caused by the Russia-Ukraine conflict, the agricultural cooperation under RCEP has played a vital role in mitigating supply chain disruptions and stabilizing regional food supplies [3]. The RCEP agreement has reshaped the agricultural landscape in the Asia-Pacific and contributed to global agricultural sustainability by fostering deeper economic integration. According to China's customs data, in 2023, China's agricultural trade with RCEP members reached $103.4 billion, a 10.3% increase from 2021, accounting for 31% of China's total agricultural trade. Of this, exports totaled $41.6 billion, representing 42.1% of China's agricultural exports, a rise of 8.2% from 2021; imports amounted to $61.8 billion, making up 26.4% of China's agricultural imports, with an 11.8% increase over 2021. The trade deficit stood at $20.2 billion, a 20.2% increase from 2021, reflecting the ongoing characteristics of China's agricultural trade—large in scale but still needing improvements in the quality, competitiveness, and efficiency of its agricultural exports. China's agricultural exports to RCEP nations primarily consist of vegetables and roots, fruits and nuts and their preparations, meat, fish, crustaceans, mollusks, and their preparations.

Digital trade, as the central form of trade in the digital economy era, has become a strategic focus in the global competition for future trade. The current wave of the information technology revolution, driven by innovations in big data, cloud computing, artificial intelligence, the Internet of Things, and other cutting-edge digital technologies, has not only led to the rise of cross-border e-commerce and digital trade in services, but also redefined the spatial aspects of international trade and the value chain. This transformation is facilitated by the free cross-border flow of data and the continuous innovation in digital infrastructure [4]. This shift has not only broadened the scope of trade but also reshaped the global rules of trade governance. The Chinese government has recognized the strategic importance of digital trade, and since the release of the Guiding Opinions on Promoting High-Quality Development of Trade in November 2019, which emphasized "accelerating the development of digital trade," the relevant policy system has been consistently refined [5]. The 14th Five-Year Plan for Digital Economy Development, issued in January 2022, further stresses the need to advance the digital transformation of trade and build an open, inclusive digital trade ecosystem by upgrading trade entities and fostering innovation in trade models through digital technology [6]. The plan also outlines measures to optimize the policy environment, enhance the support system, strengthen institutional frameworks, and improve legal protections, providing institutional guarantees for promoting digital cooperation between China and RCEP countries in agricultural trade, among other areas. The RCEP agreement, an important result of regional economic integration, incorporates a set of digital trade rules covering areas like e-commerce, services trade, investment, intellectual property, and more. It plays a key role in facilitating the cross-border flow of data, the localization of computing facilities, and the development of a digital trade system, fostering consensus on critical issues such as the free flow of data and data localization. These efforts contribute to creating a favorable environment for the growth of digital trade [7]. As a vital participant in RCEP, China views the agreement as a crucial part of building a high-quality global free trade network, and considers RCEP member countries an essential market for agricultural trade. The implementation of RCEP presents significant opportunities for China's agricultural development, especially in reducing transaction costs, optimizing product structures, and increasing export volumes, thus playing a crucial role in advancing China's agricultural industry. Previous studies have primarily focused on the impact of digital trade in services and international trade costs on product exports. Given that digital trade can effectively lower the transaction costs of agricultural products, thereby expanding export volumes, optimizing product structures, and promoting the growth of China's international agricultural trade, examining its impact on agricultural export volumes is of considerable importance.

This paper uses the stochastic frontier gravity model (SFA) to conduct empirical analysis. Using agricultural product data from HS chapters 01-24 in the UN Comtrade database, it systematically examines how the level of digital trade development in RCEP partner countries influences China's agricultural export volume. The model incorporates traditional trade gravity variables such as GDP, geographic distance, and population size, while introducing trade inefficiency factors like FTA agreements, average tariffs, and trade openness. This innovative approach constructs a dual framework that considers both technological and institutional efficiency. The study provides new insights into how digital trade drives the high-quality development of China's agricultural trade through technological empowerment and institutional innovation, offering empirical evidence for optimizing agricultural cooperation policies within the RCEP framework.

## 2. Literature Review

A number of scholars have explored the impact of digital trade on product exports from various perspectives. Freund and Weinhold (2004), Lin (2015), and Brynjolfsson (2014) all argue that digital trade positively influences the efficiency of agricultural exports [8, 9]. Additionally, research by Geomina (2014) [10], Ding, Y. (2020) [11], and Ahmedov (2020) highlights the role of the Internet as a critical information bridge in international trade [12], which effectively addresses the issue of information asymmetry in the market. This, in turn, reduces transaction costs, increases transaction volumes, optimizes resource allocation, and ultimately boosts export trade efficiency, promoting the overall growth of international trade. Chaney (2014) [13], Abeliansky (2017) [14], and Fan (2021) examine the role of the digital economy in facilitating trade [15], asserting that the digital economy can overcome information barriers and system restrictions of traditional trade, enabling precise supply-demand matching. This reduces search, matching, and communication costs, thereby expanding trade volumes and enhancing trade efficiency. Bertani (2020) conducted an in-depth analysis of trade data from European countries and found that greater investment in digital production assets significantly boosts total factor productivity [16]. Moreover, Nomaz Wanaismail (2021) demonstrated a strong positive correlation between the level of digital economy development and export trade potential and efficiency [17]. The findings suggest that as the digital economy develops, the potential for export trade increases, leading to greater export efficiency and a reduction in export inefficiencies.

In a study focused on RCEP agricultural exports, Sattayanuwa (2015) conducted a comparative analysis of commodities from various countries using the Displayed Comparative Advantage Index [18]. He concluded that the establishment of RCEP would result in both trade creation and trade diversion effects for Thai commodity imports and exports. In contrast, Xiong (2017) argued that with the implementation of the RCEP agreement and the elimination of tariffs [19], Chinese and Indian tea exporters would have the opportunity to further expand their market access in the TPP region through re-exports from Vietnam. Erokhin (2021), using fisheries as a case study, found that RCEP tariff concessions could erode the competitive advantage of some smaller Southeast Asian nations in the fisheries sector [20].

Despite extensive research on the role of digital trade in promoting international trade, existing studies predominantly focus on manufactured goods and digital services, with relatively limited attention paid to agricultural trade. Moreover, most previous analyses emphasize general indicators such as Internet penetration or e-commerce adoption, without systematically assessing the multidimensional nature of digital trade development, including digital infrastructure, security mechanisms, industrial competitiveness, and innovation capacity. Few studies specifically address how the disparities in digital trade development among RCEP member countries impact China's agricultural export efficiency.

This study addresses these gaps by constructing a comprehensive evaluation system of digital trade development, encompassing infrastructure, security, competitiveness, and innovation. It systematically analyzes how these dimensions influence China's agricultural exports under the RCEP framework. By applying a stochastic frontier gravity model to panel data from 2005 to 2022, this research offers a novel and rigorous empirical investigation into the mechanisms through which digital trade enhances agricultural export efficiency, thus contributing to the emerging literature on digital economy and international agricultural trade.

In addition to the general examination of digital trade's impact on international commerce, significant differences exist in the level of digital economy development among RCEP member countries. For instance, Singapore ranks among the world's leaders in digital infrastructure, e-commerce adoption, and data governance, whereas Indonesia faces substantial challenges related to digital connectivity and technological penetration. These disparities imply that the effects of digital trade development on agricultural exports may vary significantly across countries. However, few existing studies have explored such heterogeneity within the RCEP framework. This paper addresses this gap by incorporating the comparative differences in digital trade development into the analysis, providing a more nuanced understanding of the impact of digitalization on China's agricultural exports to diverse RCEP markets.

# 3. Empirical Model, Variable Description and Data Source

## 3.1. Data Sources

This study utilizes panel data covering China's agricultural exports to all RCEP member countries from 2005 to 2022. The dependent variable, representing the volume of China's agricultural exports, is sourced from the United Nations Trade Database. The key explanatory variable, measuring the level of digital economy development in RCEP countries, is constructed based on a set of specific indicators. In addition, various control variables, including but not limited to data from the International Telecommunication Union, the World Bank, the United Nations Conference on Trade and Development, the CEPII database, and the China Free Trade Zone Service Network, are incorporated to support the analysis.

## 3.2. Empirical Model

The theoretical foundation of the 'Trade Gravity Model' can be traced to Newton's Law of Gravity. Stochastic Frontier Analysis (SFA), initially used to evaluate the efficiency of production technologies, was later adapted for analyzing trade efficiency due to the similarities between trade activities and production functions [21]. With the rapid expansion of international trade, the application of SFA has broadened, making it one of the primary empirical tools for studying international trade issues. Since trade inefficiency may evolve over time, this study employs a time-varying stochastic frontier gravity model for analysis [22]. To account for both trade inefficiency and its influencing factors in a single model, a one-step regression strategy is applied [23]. The core explanatory variable in this model is the Digital Economy Level (DEL) of RCEP member countries. Additionally, to control for other potential influences, four control variables are incorporated: population size, GDP per capita, average tariff rates, and the geographic distance between countries. Based on these considerations, this paper constructs the following stochastic frontier gravity model:

$$\begin{aligned}\ln EXP_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} \\ +\beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \beta_5 \ln DIS_{ij} \\ +\beta_6 Z_{ij} + V_{ijt} - \mu_{ijt}\end{aligned} \tag{1}$$

Where $i$ is China, $j$ is the importer of agricultural products, and $t$ is the year; The explained variable is the total amount of agricultural products exported by China $i$ to Country $j$ in year $t$. $GDP_{it}$ and $GDP_{jt}$ represent the gross domestic product of China $i$ and $j$ in year $t$ respectively. $POP_{it}$ and $POP_{jt}$ represents the total population of China $i$ and $j$ in year $t$ respectively. $DIS_{ij}$ is the geographical distance between the two capitals. $Z_{ij}$ is other objective factors, including whether the two countries share a common language and a common border. $V_{ijt}$ is a random error term and $\mu_{ijt}$ is a trade inefficiency item.

In order to estimate the impact of the development level of digital trade of RCEP member countries on the export efficiency of China's agricultural products, the inefficiency model is constructed as follows:

$$\begin{aligned}\mu_{ijt} = \alpha_0 + \alpha_1 DEL_{jt} + \alpha_2 APEC_{ijt} \\ +\alpha_3 FTA_{ijt} + \alpha_4 TARI_{jt} \\ +\alpha_5 OPEN_{jt} + \varepsilon_{ijt}\end{aligned} \quad (2)$$

Among them, $DEL_{jt}$ represents the score of the digital trade development level of country $j$ in year $t$, the higher the score indicates that the development of digital trade of a country is more conducive to improving the trade environment and promoting the development of bilateral trade. $APEC_{ijt}$ indicates whether a country will join the Organization for Economic Cooperation and Development in year $t$. $FTA_{ijt}$ indicates whether there is a free trade agreement in force between China $i$ and $j$ in year $t$. $TARI_{jt}$ represents the import tariff rate of agricultural products in Country $j$ in year $t$. $OPEN_{jt}$ represents trade openness in Country $j$ in year $t$. $\varepsilon_{ijt}$ is a random disturbance term.

## 3.3. Variable Description

### 3.3.1. Explained Variables

$EXP_{ijt}$ represents China's agricultural exports to RCEP partner countries, where $i$ stands for China, $j$ stands for other RCEP members, and $t$ stands for year. It indicates total exports of agricultural products from China to Country $j$ by billions of dollars. The total exports of agricultural products from China to the other 11 countries are the explained variable. The data source is the UN Comtrade database, and the range of agricultural products covers the 01–24 code products under the HS code classification standard.

### 3.3.2. Core Variables

Digital trade relies on the medium of digital platforms, and with the in-depth use of digital technology, it achieves the efficient and accurate circulation of physical goods, digital products and services, digital knowledge and information [24]. Based on the definition of digital economy under the G20 framework, and with reference to the relevant research results of Ismail (2021) and Oloyede (2023) [17, 25], this study constructs a set of assessment systems for the development level of digital trade. The system covers the four core dimensions of digital infrastructure, digital safety and security mechanism, international competitiveness of digital industry and digital innovation capacity, and is further refined into 12 specific evaluation indicators, the specific composition of which is detailed in **Table 1**.

**Table 1.** Measurement Indicators of the Development Level of Digital Trade.

| Primary Index | Secondary Index | Data Source |
|---|---|---|
| Digital infrastructure | Number of mobile phone subscribers (people)<br>Fixed broadband subscribers (people)<br>Internet penetration | International Telecommunication union |
| Digital security guarantee | Number of secure web servers per million people | World Bank |
| International competitiveness of digital industry | The proportion of ICT products export | United Nations UNCTAD for Trade and Development |
| | Proportion of ICT service exports | United Nations UNCTAD for Trade and Development |
| | Exports of medium and high-tech products | World Bank |
| Digital innovation capability | Research and development expenditure as a share of GDP<br>Number of papers published in scientific journals (articles)<br>Number of resident patent applications (number)<br>Number of non-resident patent applications (number) | World Bank |

In assessing the weights of indicators at all levels of the digital economy development level, three main methodological paths exist, namely, principal component analysis, entropy value method and hierarchical analysis. Based on the reference to the research results of Zhao (2020) and Li (2021) [26, 27], this study chooses to adopt the entropy method as an analytical tool to quantitatively assess the level of digital economy development of the RCEP member countries during the period from 2005 to 2022. Specifically, the implementation steps of this measurement process are described below:

Step 1: In order to eliminate dimensional problems caused by different value ranges of 11 secondary indicators, all data are standardized by using range normalization method, as given in

$$X'_{ijt} = \frac{X_{ijt} - \min\{X_{jt}\}}{\max\{X_{jt}\} - \min\{X_{jt}\}} \tag{3}$$

Where $X'_{ijt}$ represents the data after the standardization of $j$ index in country $i$ in year $t$. $X_{ijt}$ represents the raw data of the $j$ indicator for country $i$ in year $t$, $\max\{X_{jt}\}$ and $\min\{X_{jt}\}$ represent the maximum and minimum values of the $j$ indicator for all statistical countries in year $t$.

Step 2: After the standardization of some indicators, the calculated value will be small. In order to eliminate the deviation of the calculated result, it is necessary to carry out translation processing on the standardized data. $H$ is the amplitude of the index translation, and 0.0001 is selected in this paper.

$$X''_{ijt} = X'_{ijt} + H \tag{4}$$

Step 3: Normalization of all data:

$$Y_{ijt} = \frac{X''_{ijt}}{\sum_{i=1}^{13} X''_{ijt}} \tag{5}$$

Step 4: Measure the entropy of the JTH index:

$$e_j = -\ln\left(\frac{1}{n}\sum_{i=1}^{13} Y_{ijt} \ln Y_{ijt}\right) \tag{6}$$

Step 5: Difference coefficient of the JTH index

$$g_j = 1 - e_j \tag{7}$$

Finally, the weight of the JTH indicator is:

$$W_j = \frac{g_j}{\sum_{j=1}^{11} g_j} \tag{8}$$

The final index score is obtained by multiplying the normalized data with the weights

$$del_{ijt} = \sum_{j=1}^{11} w_j X_{ijt} \tag{9}$$

According to the entropy method, the weights of each secondary index are determined, and the final scores of RCEP member countries' digital economy development level indicators are shown in **Table 2.** Japan and South Korea scored the highest in the index of digital economy development level in 2005 and 2021. In 2021, Japan's digital economy development level reached 0.1892. From 2005 to 2021, the digital economy development level of all countries showed a significant growth trend. Indonesia's digital economy development level will be the lowest among RCEP partners in 2005 and 2021, at 0.0326 and 0.0607, respectively.

**Table 2.** Scores of RCEP Partner Countries' Digital Economy Development Level Indicators in 2005 and 2021.

| | 2005 | | | | | 2021 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Country** | **Digital Infrastructure** | **Digital Security Guarantee** | **International Competitiveness of Digital Industry** | **Digital Innovation Capability** | **Total** | **Digital Infrastructure** | **Digital Security Guarantee** | **International Competitiveness of Digital Industry** | **Digital Innovation Capability** | **Total** |
| Indonesia | 0.0015 | 0.0000 | 0.0287 | 0.0023 | 0.0326 | 0.0217 | 0.0044 | 0.0280 | 0.0066 | 0.0607 |
| Singapore | 0.0158 | 0.0003 | 0.0287 | 0.0060 | 0.0508 | 0.0247 | 0.2495 | 0.0633 | 0.0093 | 0.3468 |
| New Zealand | 0.0153 | 0.0006 | 0.0127 | 0.0041 | 0.0328 | 0.0233 | 0.0298 | 0.0259 | 0.0052 | 0.0842 |
| Japan | 0.0244 | 0.0003 | 0.0244 | 0.1062 | 0.1554 | 0.0385 | 0.0379 | 0.0245 | 0.0882 | 0.1892 |
| Thailand | 0.0049 | 0.0000 | 0.0311 | 0.0038 | 0.0397 | 0.0275 | 0.0036 | 0.0240 | 0.0061 | 0.0611 |
| Australia | 0.0163 | 0.0006 | 0.0131 | 0.0183 | 0.0482 | 0.0257 | 0.0619 | 0.0267 | 0.0270 | 0.1413 |
| Philippines | 0.0027 | 0.0000 | 0.0772 | 0.0016 | 0.0814 | 0.0193 | 0.0002 | 0.0969 | 0.0025 | 0.1188 |
| Korea | 0.0217 | 0.0000 | 0.0369 | 0.0446 | 0.1031 | 0.0327 | 0.0097 | 0.0593 | 0.0667 | 0.1683 |
| Malaysia | 0.0124 | 0.0000 | 0.0642 | 0.0037 | 0.0802 | 0.0252 | 0.0141 | 0.0736 | 0.0073 | 0.1202 |

The results of the study are shown in **Figure 1**, from which it can be clearly observed that RCEP member countries show significant differences in the level of digital economy development. Specifically, Japan is the most prominent in terms of digital economy development, with the highest level reaching 0.1528; South Korea and Singapore also show strong development momentum, with both exceeding the 0.12 threshold for digital economy development. In contrast, Indonesia (0.0366), Thailand (0.0449) and New Zealand (0.0466) are lagging behind at a lower level. The mean values of the level of digital trade development in each sample country are clearly labelled in the figure. The core explanatory variable of this paper is defined as the digital trade development status of the RCEP member countries in year t. The core feature of the digital economy lies in the rapid flow of information, and the rise of digital platforms effectively reduces the costs of information collection, communication and transport in the transaction process, which significantly improves the efficiency of China's export trade. Therefore, from the perspective of theoretical expectations, the level of digital economy development and trade inefficiency should show a negative relationship.

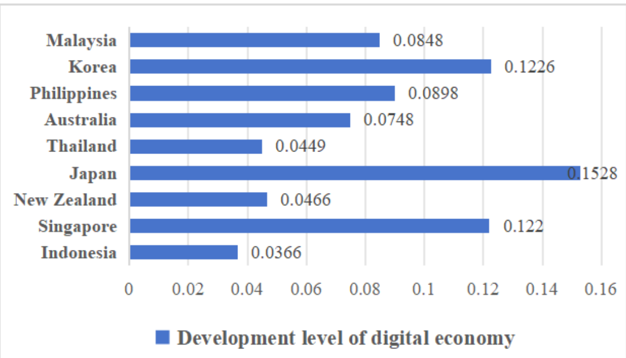

**Figure 1.** Average of Indicators of Digital Trade Development Level of RCEP Member Countries.

For instance, Singapore, ranking among the top globally in digital competitiveness, has established a robust digital infrastructure and regulatory system, enabling seamless cross-border trade processes. In contrast, Indonesia, with persistent challenges in broadband penetration and digital literacy, presents more logistical and institutional barriers to digital trade. These disparities imply that China's agricultural exports to Singapore are more efficiently facilitated through digital platforms, while exports to Indonesia may encounter higher transaction costs and slower customs clearance, hindering trade efficiency.

### 3.3.3. Control Variables

(1) Gross Domestic Product $GDP_{it}$ and $GDP_{jt}$ represent Gross domestic product of China and other RCEP member countries in year $t$, which is used to measure the level of national economic development, and the market size of RCEP partner countries is measured by this variable. The expansion of the market size is often accompanied by higher import demand, so when the per capita GDP of the importing country is at a higher level, it usually means that its citizens have stronger purchasing power, thus stimulating the growth of trade demand. Data from the World Bank.

(2) $POP_{it}$ and $POP_{jt}$ respectively represent the population size of China and RCEP member countries, data from the World Bank. Population size represents the consumption market and labor market of a country, that is, the demand and supply of a country. If labor is sufficient in RCEP member countries, the products produced will reduce the amount of products imported from abroad, provided that they meet self-sufficiency. If the domestic consumption demand of RCEP member countries is strong, under the limited supply, it will make them turn to the foreign market for consumption.

(3) $DIS_{ijt}$ indicates the distance between the capitals of China and RCEP member countries. When the distance between the two countries is farther, the cost of goods transportation is higher, which is not conducive to China's export trade, so the expectation sign is negative. $BOR_{ij}$ is a dummy variable, indicating whether China and RCEP member states have a common border. If China and RCEP member states have a common border, it can reduce transportation costs and improve the efficiency of China's agricultural exports (Huang et al. (2007))[28]. Data are derived from CEPII BACI subdatabase.

Trade inefficiency: (1) $FTA_{ijt}$ indicates whether China and RCEP members have signed a free trade agreement. When the values of dummy variables are all 1, it indicates that signing a free trade agreement is conducive to reducing trade costs and promoting trade facilitation.

(2) $OPEN_{jt}$ is the degree of trade openness of RCEP member states, the higher the degree of trade openness, the more it can reduce tariffs and trade barriers, improve the free mobility of domestic and foreign goods and resources, and promote the increase of agricultural exports to RCEP member states.

(3) $TAF_{jt}$ represents the trade barriers between the two countries, this paper takes the average tariff of various products in RCEP partner countries as a measure. The increase of tariffs in importing countries tends to increase the cost of export goods, which in turn affects export profits and leads to the reduction of trade volume. Trade openness can reduce tariffs and trade barriers and improve the free flow of domestic and foreign goods and resources, so it is expected to be negatively correlated with trade inefficiencies (Xie et al., 2022) [29]. It is the weighted average tariff of agricultural products of RCEP member countries. If the tariff of agricultural products of RCEP member countries increases, the export cost of China's agricultural products will increase, so the expectation is positively correlated with the non-efficiency of trade. Data from the World Bank.

# 4. Empirical Results and Analysis

## 4.1. Analysis of Model Results

This study uses the stochastic frontier gravity analysis method to construct a regression model for the relevant variables affecting the efficiency of China's export trade, and the results of the specific regression analysis are shown in **Table 3** below.

**Table 3.** Estimation Results of Stochastic Frontier Gravity Model.

| | Variable | Coefficient | T-Value |
|---|---|---|---|
| Random frontier term | $GDP_{it}$ | 0.602*** | 3.77 |
| | $GDP_{jt}$ | 1.043*** | 14.37 |
| | $POP_{it}$ | 0.807 | −0.22 |
| | $POP_{jt}$ | 0.244*** | 3.17 |
| | $DIS_{ijt}$ | −0.192*** | −2.58 |
| | Constant | 12.997*** | 15.46 |
| Trade inefficiencies | $DEL_{jt}$ | −1.500** | 1.68 |
| | $FTA_{ijt}$ | −0.155* | −1.9 |
| | $TAF_{jt}$ | 1.137 | 1.41 |
| | $OPEN_{jt}$ | 0.386*** | 4.76 |
| | Constant | 12.997*** | 15.46 |
| | $\gamma$ | 0.954 | 32.84 |
| | $\delta^2$ | 0.3698 | 1.63 |
| LR test value | 26.06 | | |
| Logarithmic likelihood value | 35.763 | | |
| Observed value | 162 | | |

Note: *, **, and *** are significant at the 10%, 5% and 1% levels, respectively.

The model test reveals that the LR statistic value is 26.06, which suggests a high likelihood ratio, indicating that the model fits the data well and the regression results have strong explanatory power. The parameter $\gamma$ represents the proportion of the trade inefficiency term in the stochastic perturbation, with an estimated value of 0.954, which is close to 1. This suggests a significant gap between the actual trade volume and the optimal potential trade level, with trade inefficiency being the main constraint on the export potential of Chinese agricultural products. The core factor behind this inefficiency is artificial trade barriers. The results from the time-varying stochastic frontier model show that the GDP elasticity coefficients for China and RCEP member countries are 0.602 and 1.043, respectively, both statistically significant at the 1% level. This indicates that growth in GDP on both sides positively influences the trade volume of China's agricultural exports, but the marginal impact of GDP growth in RCEP countries is much higher than in China, implying a stronger pull effect from the latter. The population size elasticity coefficient for RCEP countries is 0.244 (significant at 1%), suggesting that a larger market size in importing countries boosts external demand, leading to increased imports. On the other hand, the elasticity coefficient for China's domestic market size is not significant, implying that population growth in exporting countries does not directly improve agricultural production efficiency or export competitiveness. This highlights the reliance on other factors, such as technological inputs and trade policies, to drive exports. Finally, the elasticity coefficient for geographical distance is significantly negative at the 1% level, indicating that increased transportation costs associated with distance substantially raise export costs, thereby hindering agricultural exports.

In the empirical analysis of the trade inefficiency term, the study presents several key findings. The coefficient for the core explanatory variable, the level of digital economy development in RCEP member countries, is $-1.500$, which is statistically significant at the 5% level. This result clearly shows that the expansion of the digital economy reduces efficiency losses in the export process of China's agricultural products and boosts regional trade by lowering transaction costs. The mechanism behind this is primarily the continuous innovation in electronic communication and Internet technology, which overcomes the geographical limitations of traditional trade, enabling the efficient flow of global trade information and reducing transaction costs. Furthermore, the establishment of a fast cross-border electronic payment system within the digital economy facilitates the movement of goods in the RCEP region and strengthens trade cooperation among member countries. Additionally, digital platforms on both the supply and demand sides enable producers to track market demand in real time and precisely design export products, significantly improving the quality of exports and overall trade efficiency. The study also finds that the signing of Free Trade Agreements (FTAs) (with a coefficient of $-0.155$, significant at the 10% level) positively impacts trade efficiency. Similarly, an increase in trade openness among RCEP members (with a coefficient of 0.386, significant at the 1% level) strengthens bilateral trade relations and enhances trade efficiency. Interestingly, the weighted average tariff level of RCEP countries does not show a statistically significant effect on China's export trade efficiency. This can largely be attributed to the fact that with the acceleration of globalization and regional integration, countries increasingly rely on non-tariff measures, such as green barriers and technical barriers, to implement trade protection. As a result, non-tariff barriers are becoming a more significant constraint on China's agricultural exports.

#### 4.1.1. Robustness Test

To ensure the reliability and robustness of the baseline regression results, this study conducts multiple robustness tests using different approaches, including (1) changing the explained variable, (2) adding omitted variables, and (3) performing tail reduction on the core explanatory variable. The results of all robustness tests consistently support the main findings, confirming the stability of the conclusions (Mingyu et al., 2023) [30].

**Table 4.** Regression Results of Robustness Test.

| Variable | ln( $EXP_{ijh}/EXP_{jh}$) |
|---|---|
| $DEL_{jt}$ | $-0.681$ (0.533) |
| $GDP_{it}$ | 0.410*** (0.159) |
| $GDP_{jt}$ | 1.300*** (0.119) |
| $POP_{it}$ | $-3.945$ (3.839) |
| $POP_{jt}$ | $-6.823$*** (1.117) |
| $DIS_{ijt}$ | $-0.147$* (0.0793) |
| $FTA_{ijt}$ | $-0.359$*** (0.076) |
| $TAF_{jt}$ | 2.105** (0.827) |
| $OPEN_{jt}$ | 0.115 (0.087) |
| Constant | 11.19*** (0.811) |
| Observations | 162 |

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, the t value is in parentheses.

(1) Replacement of the Explained Variable

The explained variable is replaced by the export share of agricultural products (i.e., the proportion of exports of agricultural products from China to RCEP countries relative to the global exports of the same products). This method effectively captures the comparative advantage of China's agricultural exports. The regression results (**Table 4**) remain consistent with the baseline estimation, with the key explanatory variables maintaining the same sign and significance levels.

(2) Inclusion of an Omitted Variable

Recognizing that economic liberalization levels may influence trade flows, the Economic Freedom Index (EF) is introduced as an additional control variable. After including EF, the regression results (**Table 5**) show that the impact of the digital economy development level on China's agricultural exports remains significantly positive, demonstrating the robustness of the results against omitted variable bias.

**Table 5.** The Regression Results of Missing Variables.

| **Variable** | **lnEXP** |
|---|---|
| $DEL_{jt}$ | −0.681*** (0.533) |
| $GDP_{it}$ | 0.410*** (0.159) |
| $GDP_{jt}$ | 1.300*** (0.119) |
| $POP_{it}$ | −3.945 (3.839) |
| $POP_{jt}$ | −6.823*** (1.117) |
| $DIS_{ijt}$ | −0.147* (0.079) |
| $FTA_{ijt}$ | −0.387*** (0.081) |
| $TAF_{jt}$ | 1.874** (0.823) |
| $OPEN_{jt}$ | 0.124 (0.079)) |
| EF | 0.432 (0.65) |
| Constant | 12.44*** (0.797) |
| Observations | 162 |

Note: ***$p$ < 0.01, **$p$ < 0.05, *$p$ < 0.1, the t value is in parentheses.

**Table 6.** Shrink-Tail Regression Results of Core Explanatory Variables.

| **Variable** | **1% Tail Reduction lnEXP** | **5% Tail Reduction lnEXP** |
|---|---|---|
| $DEL_{jt}$_w | 0.281*** (3.29) | 0.396*** (2.87) |
| $GDP_{it}$ | 0.391*** (0.161) | 0.373*** (0.154) |
| $GDP_{jt}$ | 1.327*** (0.115) | 1.225*** (0.148) |
| $POP_{it}$ | −3.744 (3.522) | −3.581 (3.126) |
| $POP_{jt}$ | −6.651*** (1.205) | −5.860*** (1.143) |
| $DIS_{ijt}$ | −0.139* (0.081) | −0.125* (0.076) |
| $FTA_{ijt}$ | −0.376*** (0.073) | −0.349*** (0.069) |
| $TAF_{jt}$ | 2.041** (0.780) | 2.146** (0.716) |
| $OPEN_{jt}$ | 0.122 (0.084) | 0.103 (0.078) |
| Constant | 11.56*** (0.739) | 11.56*** (0.739) |
| Observations | 162 | 162 |

Note: ***$p$ < 0.01,**$p$ < 0.05, *$p$ < 0.1, the t value is in parentheses.

(3) Tail Reduction of the Core Explanatory Variable

To address potential biases caused by extreme values, tail reduction is conducted at the upper and lower 1% and 5% of the core explanatory variable distribution. After trimming, the re-estimated regression coefficients (**Table 6**) remain consistent with the baseline results, further confirming the robustness of the model.

Overall, the findings are stable across different model specifications and robustness checks, providing strong empirical support for the conclusions drawn in this study.

### 4.1.2. Endogeneity Test

Given the potential two-way causal relationship between agricultural export volume and the level of digital economy development, it is important to consider both directions of influence. On one hand, improvements in digital economy development can reduce export costs, thus promoting the growth of China's agricultural exports. On the other hand, higher export volumes may necessitate further advancements in the digital economy. To address this, stability and endogeneity tests are conducted, with the one-period lag of digital economy development chosen as the instrumental variable.

The table presents the results from the two-stage least squares (2SLS) method. The results show that the instrumental variables significantly affect the digital economy development level, with an F-statistic greater than the critical value of 10, indicating strong correlation between the instrumental variables and digital economy development. The P-value of the Kleibergen-Paap rk LM statistic is below 0.01, confirming that the instrumental variable passes the identification test. Additionally, the Cragg-Donald Wald F-statistics are substantially higher than the critical value, ensuring that the instrumental variable passes both the identification and weak instrument tests. Therefore, the instrumental variable is deemed valid and effective. After accounting for endogeneity, the development of the digital economy in RCEP member countries is found to have a significant positive effect on China's agricultural exports at the 1% confidence level. These results align with the findings in **Table 7**.

**Table 7.** Results of Endogeneity Test.

| Variable | 2SLS lnEXP |
|---|---|
| $DEL_{jt}$ | −0.573*** (0.518) |
| $GDP_{it}$ | 0.437*** (0.162) |
| $GDP_{jt}$ | 1.358*** (0.124) |
| $POP_{it}$ | 3.874 (3.626) |
| $POP_{jt}$ | 6.267*** (1.122) |
| $DIS_{ijt}$ | 0.140* (0.078) |
| $FTA_{ijt}$ | −0.369*** (0.076) |
| $TAF_{jt}$ | 2.092** (0.084) |
| $OPEN_{jt}$ | 0.112 (0.090) |
| Kleibergen-Paap rk LM | 0.006 (0.063) |
| Cragg-Donald Wald F | 10.072 |
| Constant | 13.26*** (0.815) |
| Observations | 162 |

Note: ***$p$ < 0.01, **$p$ < 0.05, *$p$ < 0.1, the t value is in parentheses.

## 4.2. Heterogeneity Analysis

### 4.2.1. Country Heterogeneity Analysis

This study employs the stochastic frontier gravity model to assess the average efficiency of China's agricultural exports to RCEP member countries, with the results illustrated in **Figure 2**. The analysis reveals that the efficiency of China's agricultural exports to different RCEP countries ranges between 0.186 and 0.946. Within this range, higher values indicate better trade export efficiency, while lower values suggest greater potential for trade expansion. Following the methodology outlined by Ravishankar, G., & Stack, M. M. (2014) [31], the countries are categorized into four market types based on the average export efficiency: iceberg (0–0.3), developmental (0.3–0.6), expansionary (0.6–0.9), and saturated (0.9–1.0). Notably, Malaysia ranks first in terms of trade efficiency with an impressive score of 0.945. This advantage is primarily attributed to Malaysia's leadership in the digital transformation among ASEAN countries [32]. The trade efficiency of China's agricultural exports to the Philippines and Thailand is 0.555 and 0.481, respectively. Exports to the Philippines are dominated by edible vegetables, fruits, and nuts, while most agricultural exports to Thailand consist of tropical fruits [33]. The trade between China and Thailand not only reflects their deep agricultural cooperation but also highlights the complementary nature of their agricultural products, meeting the needs of consumers in both countries. On the other hand, China's export efficiency to Australia is the lowest at 0.178. This is due to a significant imbalance in bilateral agricultural trade, with China predominantly importing agricultural products from Australia, while its exports to Australia remain limited. This indicates that the potential for agricultural trade between the two nations still needs further exploration. China's agricultural export efficiency to Japan and South Korea is 0.186 and 0.205, respectively. For Japan, despite its reliance on imports due to its geographical constraints, high tariffs, non-tariff barriers, and strict import controls limit China's agricultural exports to Japan. In the case of South Korea, the rise in trade protectionism since 2008, coupled with the effects of political events such as the Saad incident and South Korea's stringent agricultural protection measures, has led to a decline in the efficiency of China's agricultural exports to the country.

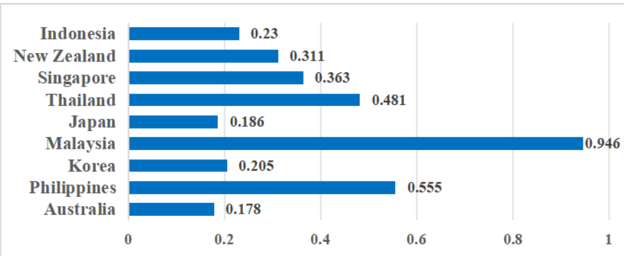

**Figure 2.** Average Value of China's Agricultural Export Efficiency to RCEP Member Countries.

### 4.2.2. Product Heterogeneity Analysis

In addition to country-level heterogeneity, this study also examines product-level heterogeneity to assess whether the impact of digital economy development varies across different categories of agricultural products. Specifically, the agricultural exports are grouped into three major categories:

(1) Edible vegetables and roots (HS07–08),
(2) Fruits and nuts (HS08),
(3) Animal products including meat and seafood (HS01–05).

Separate regressions are conducted for each product category. The results show that the positive effect of digital economy development on China's agricultural exports is most pronounced in the export of fruits and nuts, followed by vegetables and roots, while the impact is relatively weaker for animal products.

This indicates that products with higher perishability and greater dependency on logistics and information systems (such as fresh fruits and vegetables) benefit more significantly from improvements in the digital trade environment. In contrast, animal product exports are less sensitive to digital trade facilitation, possibly due to stricter quarantine regulations and non-tariff barriers.

These findings highlight that digital trade development not only influences overall agricultural exports but also has differentiated effects across different product types, emphasizing the need for targeted strategies to promote digital-enabled agricultural trade.

### 4.3. Mediation Effect Test

### The Role of Information Cost Reductionn

To further explore the mechanism through which digital trade affects China's agricultural exports, a mediation effect model is constructed using "information cost reduction" as the mediating variable. This variable is proxied by the number of secure web servers and internet penetration rate. The mediation test follows a three-step regression approach. Results show that digital trade significantly reduces information costs ($p < 0.05$), and reduced information costs significantly enhance export efficiency ($p < 0.01$). Moreover, the indirect effect accounts for approximately 32% of the total effect, confirming that part of digital trade's impact operates through mitigating information asymmetry.

## 5. Conclusions and Policy Recommendations

This study uses the agricultural export values of RCEP member countries as the data sample and develops a comprehensive evaluation system to measure the level of digital economy development. The system focuses on key dimensions such as the completeness of digital infrastructure, digital security capabilities, the international competitiveness of the digital industry, and the capacity for digital innovation. The entropy value method is employed to assign appropriate weights to the indicators. The analysis reveals notable regional differences in the digital economy development levels among RCEP countries. Singapore, Japan, and South Korea occupy the top three positions due to their strong performance in digital infrastructure, security, industry competitiveness, and innovation. In contrast, countries like

Indonesia and Thailand are lagging in terms of digital economy development. From a dynamic perspective, while the level of digital economy development in each member country fluctuates annually, there is an overall upward trend. This indicates significant potential for further digital economy growth within the RCEP region, and suggests that strengthened regional cooperation and policy coordination will likely foster continued synergistic development of the digital economy among member countries in the future.

Notably, the entry into force of the RCEP agreement in 2022 marked a turning point in regional digital trade integration. A comparative analysis of digital trade development before and after RCEP's implementation shows accelerated growth in China's agricultural exports to digitally advanced RCEP members, particularly in 2022 and 2023. This reflects the early benefits of enhanced regulatory harmonization, digital customs procedures, and greater trust in data flows under RCEP's digital trade chapter.

This study uses the stochastic frontier gravity model to examine how the level of digital economy development in RCEP member countries affects China's agricultural export trade. The findings show that improvements in digital trade development within RCEP countries can significantly mitigate the negative impact of trade inefficiencies, thus positively influencing the export efficiency of Chinese agricultural products. This effect is largely due to the fact that higher levels of digital economy development in importing countries help reduce trade costs, thereby enhancing trade efficiency. Regarding control variables, the study further reveals that the economic size of China and RCEP member countries, the population size of importing countries, and the trade openness of these countries all positively contribute to China's agricultural exports to RCEP members at the 1% significance level. Additionally, the coefficient for the FTA signing variable is negative at the 10% significance level, suggesting that the trade agreements between China and RCEP members help to significantly reduce trade barriers, improving the efficiency of agricultural exports. However, the geographical distance between China and RCEP countries has a notably negative impact on agricultural exports. This is mainly due to the increased transportation costs associated with greater distance, which in turn raises the overall export costs. Notably, China's population size does not have a significant effect on promoting agricultural exports. This could be attributed to the high domestic demand, where most products and services are consumed domestically, reducing the surplus available for export. Furthermore, tariff concessions by RCEP member countries do not significantly boost China's agricultural exports, likely because these countries have implemented complex non-tariff barriers to protect their own agricultural sectors, thereby restricting China's exports.

Based on the above conclusions, this paper draws the following three enlightenment.

**(1) Deepen digital infrastructure cooperation between China and RCEP partner countries to consolidate the foundation for the development of agricultural export trade.**

The development of transport infrastructure, including railways, roads, and ports, forms the foundation for international trade and the digital economy. Among RCEP members, countries like Japan and Thailand, with strong economic foundations, have relatively advanced digital economy development and well-established infrastructure. In contrast, less developed countries in the region face lower levels of digital trade. To support these nations, the Chinese government can offer financial assistance through loans or investments, dispatch expert teams to provide technical support, and offer training in planning, designing, and building digital infrastructure, helping these countries establish fast, reliable, and secure digital systems.

**(2) Promoting the construction of digital cooperation platforms with RCEP partner countries**

Given the uneven development of the digital economy across the region, the "digital divide" presents a significant challenge to economic and trade cooperation between China and some RCEP members in the agricultural sector. To overcome this, the Chinese government should take proactive steps to help countries in the region build a shared future in cyberspace. On one hand, as China integrates into the global digital governance framework, it should also collaborate with RCEP countries to create a digital platform, promote the development of digital regulations, and assist RCEP members in adopting tailored development models that suit their national contexts, thereby reducing the digital divide. On the other hand, China's leading position in digital economy and technology allows it to offer both financial and technical support to RCEP members with less advanced digital economies. China can also share its experiences in digital technology innovation to help these countries improve their digital economy development. Moreover, China should strengthen cooperation on agricultural digitization with RCEP members, facilitating the integration of digital technology with agriculture to boost the total factor productivity of agricultural products and share the benefits of digital advancements. Ultimately, through collaborative efforts from governments, enterprises, and other stakeholders, a regional digital platform under RCEP can be established, helping to bridge the digital divide, enhance regional economic competitiveness, and lay a strong foundation for a more integrated community with a shared future.

**(3) Refine policy measures into short-term and long-term strategies for digital transformation of agricultural exports**

To reduce trade costs and improve export efficiency, it is essential to adopt a dual-pronged policy approach that includes both short-term and long-term strategies [2]. In the short term, efforts should focus on establishing and enhancing cross-border e-commerce platforms specifically for agricultural products, improving digital logistics systems, and streamlining electronic customs clearance procedures [34]. These immediate actions can quickly lower transaction barriers, promote direct access to foreign markets, and enhance trade convenience for exporters. In the long term, China should collaborate with RCEP partners to invest in digital infrastructure, such as broadband networks, data centers, and secure digital payment systems [35]. These infrastructure upgrades will form the foundation for a more resilient and efficient digital trade ecosystem. Moreover, sustained cooperation in digital governance standards, data interoperability, and cybersecurity protocols will ensure that the benefits of digital trade are equitably shared among all RCEP members, fostering inclusive growth in regional agricultural trade.

## Author Contributions

L.Z.: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing–original draft, Writing–review & editing; A.A.G.H.: Conceptualization, Methodology, Validation, Supervision, Project administration, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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## Data Availability Statement

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## Conflicts of Interest

The authors declare no conflict of interest, no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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