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How e-commerce can boost China's high-quality agricultural exports

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Introduction: Export quality improvement is a crucial path for a country or region to climb up the advanced division of labor in the global value chain. For developing countries that have long been at the lower end of the global value chain division of labor, the dominance of agricultural trade is often controlled by international retailers, leading to higher costs of agricultural trade and hindering the upgrading of the quality of agricultural exports. As a traditional agricultural exporting country, China still needs a competitive advantage despite the large scale of its agricultural exports. Currently, e-commerce can provide buyers and sellers with comprehensive transaction information and technical support, allowing them to realize rational allocation of resources and export upgrading. Therefore, studying how e-commerce can promote the quality upgrade of agricultural exports is crucial for China to build a trade power.

Methods: This paper clarifies the mechanism of e-commerce's theoretical impact on the quality of agricultural exports and then empirically tests it using a high-dimensional fixed-effects model with Chinese customs data from 2000 to 2020 as a sample.

Results: The results show that e-commerce significantly promotes the quality of agricultural exports in all regions of China, and this conclusion still holds after various robustness tests; the heterogeneity test shows that e-commerce fosters the quality of agricultural exports in eastern China, densely populated regions, and economically underdeveloped regions, especially in the case of heterogeneous products; the mechanism analysis confirms that e-commerce promotes the quality of agricultural exports mainly through the optimization of the agricultural industry chain and supply chain, and the enhancement of the level of servicing. Mechanism analysis confirms that e-commerce improves agricultural export quality mainly through optimizing the agricultural industry chain and supply chain, improving the level of servitization, and docking the demand information of the consumer market, etc. Expanded analysis shows that constructing cross-border e-commerce platforms also significantly improves the quality of micro enterprises' agricultural exports. This paper enriches the research on e-commerce and agricultural trade.

Discussion: This paper provides an essential reference for constructing a robust agricultural trade country and developing high-quality agriculture. Despite encompassing data up to 2020, in the context of today's global economic volatility directly affecting agricultural trade, future investigations will broaden the scope to delve deeper into how e-commerce can help countries cope with global economic uncertainty.

KEYWORDS

e-commerce, agricultural export quality, entropy weight method, high latitude fixed effects model, difference-in-differences model

1 Introduction

Agriculture, the cornerstone of the national economy, plays an essential role in developing human society (Stefanovic et al., 2020). China, a country with a long-standing history of agricultural exports, has witnessed a significant increase in its total export trade since becoming a member of the World Trade Organization in 2001. The agricultural trade has grown from US$16.1 billion in 2001 to US$98.93 billion by the end of 2023, covering as many as 186 countries and exporting up to 887 different types of products annually.[1] Although the value of China's agricultural exports has been increasing yearly, the quality of agricultural exports remains low. With the rising market access thresholds for agricultural products in destination country markets, such as inspection and quarantine barriers, identity certification barriers, green trade barriers, etc., agricultural exports risk being returned or detained. In 2023, the U.S. Food and Drug Administration (FDA) refused to import Chinese agricultural products because they contained contaminated or deteriorated substances, and the European Union's Rapid Alert System for Food and Feed (RASFF) notified imports of agricultural products from China that had pesticide residues, among other problems.[2] Therefore, the quality improvement of agricultural exports is crucial for building a solid agricultural country (Zhou et al., 2023).

As an economic activity centered on network information, e-commerce plays a vital role in reducing information asymmetry in the trade process, achieving optimal allocation of resources, and enhancing export competitiveness. In recent years, e-commerce has increased in China, with e-commerce turnover reaching a high of $6 trillion by 2022, up 3.5 percent year-on-year.[3] E-commerce has become an essential part of farmers' productive lives in the context of the rapid development of digital technologies such as cloud computing, big data, and the Internet of Things (Couture et al., 2021). To this end, using e-commerce to improve agricultural exports will become an important initiative to enhance agricultural productivity and the international competitiveness of agricultural products, ensure food security, and promote high-quality agricultural development.

This paper attempts to systematically assess the impact of e-commerce development on the export quality of agricultural products in various regions of China through a high-dimensional fixed-effects model using Chinese customs data from 2000 to 2020. The marginal contributions of this paper are mainly in the following areas:

Firstly, the indicators are more precise. This paper uses the China Customs Database from 2000 to 2020 to measure the quality of agricultural exports at the HS 6-digit level in 31 regions of China. Compared with the previous literature, which mainly adopts the rough measurement method of UNcomtrade data, this paper starts from the actual situation of the difference in the degree of economic development of each region of China. It carries out a more detailed measurement of the quality of agricultural exports in each area of China, which, to a certain extent, enriches the relevant research on the quality of agricultural exports of developing countries. To a certain extent, this paper improves the research on the quality of agricultural exports of developing countries. Secondly, the research perspective has become more in-depth. This paper systematically examines the impact and mechanism of e-commerce on the export quality of agricultural products, expands the research on e-commerce and agricultural trade, and provides essential references for constructing a solid agricultural trade country and the high-quality development of agriculture. Thirdly, the empirical evidence is more diverse. This paper examines the impact of e-commerce on the quality of agricultural exports from both macro and micro perspectives, providing more prosperous and more robust empirical evidence for an in-depth understanding of e-commerce's impact on agricultural export quality enhancement.

The rest of the paper is organized as follows: in the second section, we explore the literature review and research hypotheses; in the third section, we present the model set-up and variable descriptions; in the fourth section, we analyze the regression results; in the fifth section we offer the discussion; and in the sixth section, we draw conclusions.

2 Literature review and research hypothesis

As an intangible attribute of a product, product quality is emphasized as a vertical difference within a product, i.e., an objective characteristic that comes from the same type of differentiated product (Amiti and Khandelwal, 2013). The improvement of the quality of export products determines the size of the national competitiveness of a country or region participating in the international trade process and, at the same time, becomes an essential way for the country or region to climb up the advanced division of labor in the global value chain (Teixeira and Queirós, 2016). For developing countries, which have long been at the lower end of the global value chain, the dominance of agricultural trade has been dominated by international retailers, who have used their purchasing power and consumer branding advantages to continuously demand cost reductions and higher standards from supplier countries, resulting in higher and higher costs for developing countries' agricultural exports (Lee et al., 2012). In addition, coupled with the characteristics of agricultural products, which are highly seasonal, territorial, diverse, and perishable, they are susceptible to information searching and cross-border logistics costs (Reimer, 2008). As a traditionally large agricultural exporter, China has not capitalized on its large export volume to create economies of scale and also lacks a competitive export advantage (Fan et al., 2023; Wang et al., 2023).

E-commerce, a transactional activity between buyers and sellers, consists of all transactional information and technical support between buyers and sellers before and after a business transaction

1 Data on China's agricultural exports in 2001 were from the Ministry of Agriculture of the People's Republic of China, *http://www.moa.gov.cn/xw/zwdt/200408/t20040805_229417.htm.*; the data on China's agricultural exports in 2023 were from the Ministry of Commerce of the People's Republic of China, *http://wms. mofcom.gov.cn/article/zt_ncp/table/2023_12.pdf.*; the data on China's agricultural exports by category and country were our calculations based on China's customs data.

2 Data from "China's Export of Consumer Products, Agri-Food, and Medical Device Products to Europe and the United States in 2023" was published by Beijing Customs of the People's Republic of China, *http://xiamen.customs.gov.cn/beijing_customs/ztzl1/jgjmzl/gzld43/5689535/index.html*.

3 Data from "China Electronics Report (2022)" was published by the Ministry of Commerce of the People's Republic of China, *http://dzsws.mofcom.gov.cn/article/ztxx/ndbg/202306/20230603415404.shtml*.

(Popescu and Popescu, 2007). With the cross-border flow of data and the establishment of international unified platforms, the role of e-commerce in the trade field is becoming increasingly important. Gregory et al. (2019) argue that e-commerce can effectively reduce information asymmetry in the trade process and achieve the optimal allocation of resources across countries. The United States Department of Agriculture (USDA) has pointed out that e-commerce has four core agricultural functions: information dissemination, input supply, commodity trading platform, and logistics and supply chain management (Shu et al., 2007). These functions provide support for the export of agricultural products and lay the foundation for upgrading the quality of agricultural exports. Zhou et al. (2023) further state that China's cross-border e-commerce industrial policy implementation promotes agricultural export quality improvement through export competition and export learning effects. Considering the above literature, this paper argues that the rapid development of e-commerce effectively facilitates improving the quality of agricultural exports. To this end, this paper clarifies the theoretical mechanism of e-commerce and agricultural export quality improvement from the perspectives of domestic agricultural supply and foreign agricultural demand.

From a production point of view, e-commerce enables the supply of high-quality agricultural exports at the supply level. E-commerce helps to put data and information and other factors of production in the role of the agricultural output, accelerate the dissemination of agricultural production technology and regional agricultural information, enhance agricultural productivity, and promote the transformation and upgrading of agricultural modernization, such as the emergence of rural industrial parks or new rural co-operative organizations, to realize the transformation of agriculture from the traditional crude to the intensive mode of operation through industrial agglomeration, and to expand the boundaries of the possibilities of agricultural production by using large-scale production, to Expanding the scale and competitive advantage of agricultural exports (Krugman, 1980; Kastratović and Bjelić, 2022). As the scale of agricultural exports increases, the cost of trade per unit of agricultural products decreases and the margin of agricultural export intensification increases (Hosseini et al., 2019). At the same time, e-commerce can break the restrictions of traditional trade barriers such as distance, information, and language. Through diversified exports, platforms tap into new markets for agricultural exports, reduce the fixed costs of agricultural exports, and realize the expansion of expansion margins (Gomez-Herrera et al., 2014). In addition, e-commerce's role in reducing trade costs is reflected in cross-border logistics costs (Gessner and Snodgrass, 2015), organizational coordination costs (Chandrasekar Subramaniam, 2002), and menu costs (Brynjolfsson and Smith, 2000), among others. To sum up, e-commerce accelerates the dissemination of agricultural production technology through data and information integration and sharing, enhances agricultural productivity, and shifts agricultural production from extensive development to intensive and large-scale production, thus enhancing the efficiency of agricultural production and the quality of supply. At the same time, e-commerce reduces the cost of agricultural trade, realizes the effective allocation of resources, and promotes the upgrading of the quality of agricultural exports.

From a demand perspective, the production of agricultural products is more dispersed than industrial manufactured goods, with distinct geographical characteristics. At the same time, demand for agricultural products also varies according to the regional distribution and agricultural production capacity of different countries. In the international trade of agricultural products, the mismatch between supply and demand is frequent. E-commerce can effectively enhance new ways for agricultural exports through the e-commerce platform to achieve the precise match between traditional agricultural export enterprises and consumers in the destination country and to reduce the intermediate links such as searching, matching, negotiation, and contract signing (Lendle et al., 2016). In addition, the development of e-commerce can further break through the limitations of traditional trade objects and achieve flexible matching between consumers, wholesalers, retailers, and manufacturers, effectively meeting consumers' demand in destination countries for differentiated agricultural products (Curo et al., 2020). According to the theory of "demand-led innovation," the demand of the potential market will stimulate enterprises to innovate, and enterprises will maintain their competitive advantage in exporting by producing differentiated and high-quality products to cope with the uncertainty they face in the future (Matsuyama, 2002). E-commerce can lead to demand for high-quality agricultural products at the demand level. In short, e-commerce is the process of achieving the flexible matching of consumers, wholesalers, retailers, and manufacturers; farmers or enterprises can follow the consumer preferences of the international market to carry out customized production to meet the market demand for high-quality agricultural products, and to promote the upgrading of the quality of agricultural exports.

> *H*1: E-commerce positively contributes to the quality improvement of agricultural exports.

In the upper reaches of the agricultural industry chain, e-commerce enterprises establish cooperative relationships with agricultural production cooperatives or farmers through order-based or contractual production to optimize and adjust input factors such as seeds, fertilizers, and pesticides. In addition, e-commerce can further deepen the input of research and development, technology, and information factors, realize the extension of the agricultural industry chain, and change the agricultural production mode from the traditional "experience-oriented" to "data-oriented" (Zeng et al., 2019). In the middle reaches of the agricultural industry chain, with the establishment of the e-commerce trading platform, the input information of the upper reaches of the agricultural industry chain and the differentiated demand of the lower reaches are transmitted to the agricultural product processing enterprises through the feedback mechanism of the platform, to realize the timely and effective matching of production information. In addition, in the process of processing agricultural products, the e-commerce platform guarantees the quality of agricultural products by setting up a standardized management system for product inspection, supply guarantee, organic traceability, high-end branding, and other norms (Li et al., 2020). In the downstream of the agricultural industry chain, e-commerce will further play its productive service functions, such as in the transport link, e-commerce through the use of intelligent logistics and cold chain management technology to reduce the logistics costs of agricultural products and improve the efficiency of agricultural products transport; in the sales link, through e-commerce live broadcasting, to achieve the diversification of sales channels for agricultural products; energy saving and green environmental

protection link, e-commerce through the transparent publicity of the use of chemical pesticides and fertilizers in the process of agricultural products planting In the energy-saving and green ecological protection segment, e-commerce increases consumer confidence in agricultural products by transparently disclosing the use of chemical pesticides and fertilizers during the cultivation process of agricultural products, thus realizing the high-quality development of agricultural products (Tao et al., 2021). E-commerce integrates agricultural science and technology, transport and storage, information, finance, environmental protection, education, wholesale and production service support, and other service activities to transform and upgrade agriculture and promote the quality of agricultural exports. E-commerce through information sharing, technological innovation, resource integration, and other productive service activities to open up the agricultural industry chain upstream, midstream, and downstream links, constantly promote the optimization and upgrading of the agricultural industry, increase the overall export competitiveness of the agricultural industry chain, and achieve the quality of agricultural products for export.

> *H2*: In the agricultural business system, e-commerce can upgrade the quality of agricultural exports by modernizing the agricultural industry chain and supply chain.

> *H3*: From the perspective of production services, e-commerce can promote the transformation and upgrading of agriculture by upgrading the level of productive services and promoting the quality of agricultural exports.

From the perspective of the domestic market, through Taobao, Jingdong, Pinduoduo, and other e-commerce platforms, it breaks the traditional regional restrictions on the circulation of agricultural products, integrates the information of dispersed farmers in various regions of the country, and realizes the disclosure of information on agricultural products in the multiple areas, product specifications, and the unification of logistics and services. E-commerce platforms can record, publish, and distribute timely information on the quality of produce, the size of suppliers, and consumer preferences. Establishing a unified market mechanism and trading rules for agricultural products in all country regions is conducive to the branding effect and the formation of unique agricultural products in each area, such as geographical indications. Products with geographical indications have quality assurance (Crozet et al., 2012). They are more likely to be recognized by consumers, which is conducive to giving full play to the vitality of the domestic market, meeting the demand of domestic consumers for high-quality agricultural products, and enhancing the competitive advantage of agricultural exports. From the perspective of foreign markets, the traditional agricultural trade is relatively homogeneous, mainly relying on large containers for trade; coupled with the fact that agricultural producers do not have a complete grasp of the information on consumer demand in the destination country, the phenomenon of homogenization of agricultural exports is becoming more and more serious. As consumers continue diversifying their preferences, the market will become more refined. E-commerce can effectively bring together a large number of sellers and buyers in overseas markets on the same platform, reduce the traditional online inquiry, negotiation, contract signing and payment and settlement of the two sides of the intermediary links in the trade, reduce the cost of searching for information, and realize an effective match between buyers and sellers in exporting and importing countries (Srinivasan et al., 2002; Lendle et al., 2016). In addition, agricultural producers can flexibly produce according to the differentiated preferences of consumers in the destination country in a timely and efficient manner (Valarezo et al., 2018). For example, Alibaba International offers differentiated products to consumers by analyzing buyers' consumption history and interest preferences through big data and artificial intelligence. Firms seeking to satisfy mature, non-saturated, differentiated consumer demand with a relatively high willingness to pay will choose to employ innovative strategies to maintain niche market share. E-commerce can effectively help agricultural producers grasp the preferences of agricultural products in the markets of the destination countries and flexibly adjust their production strategies accordingly to optimize the product structure and achieve quality upgrading of agricultural exports.

> *H4*: In the circulation of agricultural products, e-commerce can accurately obtain information on the demand for agricultural products in the destination countries, realize the expansion of the agricultural market and the docking of supply and demand, and promote the quality of agricultural products for export.

3 Model setting and description of variables

3.1 Modeling

To more effectively identify the impact of e-commerce on the quality upgrade of China's agricultural exports and to address the bias problem of omitted variables arising from not varying over time but varying over individuals and not varying over individuals but varying over time, this paper adopts a high-dimensional fixed-effects model to conduct empirical analyses to reduce the computational complexity, improving the estimation efficiency, and enhancing the model's reliability and explanatory power (Belloni et al., 2014). In addition, this paper further controls for joint fixed effects based on a high-dimensional fixed effects model, aiming to eliminate the potential impact of unobservable factors that change simultaneously over time and individually on the regression results. Based on existing studies, we set the econometric model as Eq. (1):

$$\begin{aligned} lnquality\_distance_{tjkh} = {} & lnEC_{tj} + \ln arg\_DEVT_{tj} + \\ & lnOpen\_proid_{tj} + lnpergdp\_ \\ & proid_{tj} + lnOpen\_country_{tk} + \\ & lnpergdp\_country_{tk} + Belt_{tkj} + \\ & \delta_{th} + \delta_{jhk} + \epsilon_{tjkh} \end{aligned} \quad (1)$$

where $lnquality\_distance_{tjkh}$ denotes the export quality of h agricultural products exported from China's j region to the k destination country in year t; $lnEC_{tj}$ denotes the level of e-commerce development in China's region j in year t; $\ln arg\_DEVT_{tj}$ denotes the indicator of high-quality development of agriculture in China's region j in year t (the categorization of the indicator is shown in Schedule 1);

$lnOpen\_proid_{tj}$ denotes the degree of openness of China's region j in year t, i.e., it is measured by the ratio of trade imports and exports of each region to GDP; $lnOpen\_country_{tk}$ denotes the degree of openness of the destination country k in year t, i.e., it is measured by the ratio of the destination country's trade imports and exports to its GDP; $Belt_{tkj}$ denotes the dummy variable of country's participation in the Belt and Road Initiative, if destination country i signed the Belt and Road Initiative with China in year t, the dummy variable $Belt_{tkj}$ will take the value of 1, otherwise it will take the value of 0. δ_{th} denotes year and product joint fixed effects; δ_{jhk} denotes China's export region, product and destination country joint fixed effects; ϵ_{tjkh} is a random perturbation term. In this paper, all the variables involving trade amounts are uniformly expressed in RMB according to the exchange rate between USD and RMB in each year. In addition, all non-dichotomous variables in the regression are logarithmically treated by adding 1.

3.2 Data description

3.2.1 Classification of agricultural products

There are currently three main global versions of agricultural products classification, namely the Standard International Trade Classification (SITC codes), the Broad Economic Categories Classification (BEC codes) and the Harmonized Commodity Description and Coding System (HS codes). In addition, there are two main classifications of global agricultural products, the World Trade Organization (WTO) and the Food and Agriculture Organization of the United Nations (FAO), both based on SITC codes, which may overestimate the trade balance in agricultural products (Fan et al., 2023). At the same time, it is easy to ignore agricultural export heterogeneity. This is if the total trade in agricultural products is aggregated using HS codes 1 to 24 chapters. Due to the large number of countries to which China exports, many countries' trade with China may focus on a few specific types of agricultural products. This may affect the accuracy of the results if a macro perspective is used to examine agricultural exports. Therefore, this paper draws on Fan et al.'s classification criteria (2023) classified agricultural products as "Uruguay Round Agreement on Agriculture + fish products + primary forest products."

3.2.2 Data sources

The data used in this paper to measure the quality of agricultural products comes from the product trade database of the General Administration of Customs of China from 2000 to 2020, which provides all the information on China's foreign imports and exports from 2000 to 2020, and contains information on the financial and quantitative aspects of product exports, as well as the country of export destination. Indicators at all levels of e-commerce development, indicators at all levels of high-quality agricultural development, GDP *per capita*, and trade openness in China's regions are from the China E-Commerce Report, China Rural Statistical Yearbook, and China Statistical Yearbook, respectively. Destination country GDP *per capita* and destination country trade openness are from the World Bank WDI database. Information on countries with which China has signed "Belt and Road" agreements comes from the Chinese Ministry of Commerce. Country distances and exports are from CEPII's BACI database. China's level of agricultural servicing is from the OECD-ICIOD input–output database.

3.3 Description of variables

3.3.1 Agricultural export quality measurements

Regarding agricultural export quality measurement, this paper draws on the KSW methodology of Khandelwal et al. (2013).

First set the destination country consumer effect function U_i as Eq. (2):

$$U_i = \left[\int_{h=1}^{\Omega} \left(\gamma_{iht} q_{iht}\right)^{\frac{(\sigma-1)}{\sigma}} dh\right]^{\frac{\sigma}{(\sigma-1)}} \tag{2}$$

where i is the export destination country, h is agricultural products, t is time, Ω represents the types of agricultural products that can be consumed by consumers in the export destination country i, σ is the elasticity of substitution between agricultural products ($\sigma > 1$), γ_{iht} represents the quality of agricultural products h imported by country i in year t, and q_{iht} represents the quantity of agricultural products h imported by country i in year t.

The importer's budget constraint is:

$$\int_{h=1}^{\Omega} p_{iht} q_{iht} dh = Y_{it} \tag{3}$$

where p_{iht} represents the import price of agricultural product h in country i in year t, and Y_{it} represents all of country i's import revenue spent on agricultural products in year t.

Solve (1) to the maximum extent possible under (2) budget constraints.[4]

$$q_{iht} = Y_{it} P_{it}^{\sigma-1} \left(\gamma_{iht}\right)^{\sigma-1} \left(p_{iht}\right)^{-\sigma} \tag{4}$$

The logarithms of both sides of Equation (3) can be written in the logarithmic form of Equation (5):

$$\ln q_{iht} = \ln Y_{it} + (\sigma-1) lnP_{it} + (\sigma-1) \ln \gamma_{iht} - \sigma lnp_{iht} \tag{5}$$

Taking the logarithm on both sides of Equation (4) yields the logarithmic form of Equation (6):

$$\ln q_{iht} + \sigma lnp_{iht} = \ln Y_{it} + (\sigma-1) lnP_{it} + (\sigma-1) \ln \gamma_{iht} \tag{6}$$

Quality equations control unobservable or omitted variables by introducing fixed effects at the year, destination and product levels.

4 $P_{it} = \int_{h=1}^{\Omega} (p_{iht} / \gamma_{iht})^{1-\sigma} dh^{\frac{1}{1-\sigma}}$, it represents the overall price level in the export destination country i in year t.

The equation for measuring agricultural export quality is further improved as Equation (7):[5]

$$\ln q_{iht} + \sigma ln p_{iht} = \varphi_h + \varphi_{it} + \varepsilon_{hit} \quad (7)$$

The quality of agricultural exports ($quality_{iht}$) can be obtained by dividing the residuals of agricultural products quality by ($\sigma - 1$). In order to make the quality of different products comparable, this paper standardizes the quality of agricultural products exported each year (HS6 digits) with the maximum value of $quality_{ht,\max}$ and the minimum amount of $quality_{ht,\min}$ respectively.

In addition, considering that there may be a "Washington apple benefit" in agricultural exports, i.e., the quality of agricultural exports may be correlated with trade costs (Borcherding and Silberberg, 1978, p. 131). In this paper, we construct instrumental variables for agricultural export prices based on the distance from China to the destination country. These variables are adjusted by the weights of the proportion of agricultural exports from each Chinese province to the destination country in different years.

3.3.2 E-commerce measurement

In this paper, indicators are selected from three aspects of e-commerce readiness, e-commerce usage and e-commerce influence in Chinese provinces, and comprehensive indicators of e-commerce in Chinese provinces are constructed by the entropy weight method. The entropy weight method measures the comprehensive indicators of the target layer through indicators fluctuation:

(1) As shown in Equations 8, 9, standardize indicators across different dimensions

$$x_{ij}^{*} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \left(positive\ indicator \right). \quad (8)$$

$$x_{ij}^{*} = \frac{maxx_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \left(Negative\ indicator \right). \quad (9)$$

Where x_{ij} denotes the raw data of j indicators in region i of China, $\min x_{ij}$ is the minimum value of the indicator, $\max x_{ij}$ is the maximum value of the indicator, and x_{ij}^{*} is the result after standardization of indicator x_{ij} .

(2) Calculation of the share of indicator j in region i of China as Equation (10).

$$X_{kij} = \frac{x_{kij}^{*}}{\sum_{i=1}^{n} x_{kij}^{*}} \quad (10)$$

China's X_{kij} represents the weight of indicator j in province i in year k.

(3) Calculate the information entropy of the indicator e_j as Equation (11).

$$e_j = -\frac{1}{\log_n} \sum_{j=1}^{m} X_{ij} * \log X_{ij} \quad (11)$$

e_j is the information entropy of the j indicator, and n is the number of provinces evaluated, $n = 31$.

(4) Calculate the coefficient of variation g_j of the jth indicator according to Equation (12), and subsequently calculate its weight w_j using Equation (13).

$$g_j = 1 - e_j \quad (12)$$

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \quad (13)$$

g_j is the coefficient of variation for indicator j. The larger the coefficient, the more significant the indicator is to the object of study and the more significant the economic indicator is.

(5) Weight and sum the standardized indicators in (1) according to the weights calculated in (4) to obtain a composite e-commerce indicator.

(6) Repeat steps (1) to (5) depending on the year (Table 1).

3.4 Characteristic facts

In accordance with the above methodology, this paper measures the export quality of 1,092 agricultural products separately from 2000 to 2020. To understand differential changes in agricultural export quality, this paper plots the average annual trend of changes in agricultural export quality. This is in the livestock, fisheries, forestry and plantation sectors, respectively (Table 2, Figure 1). Agricultural exports from different industries have shown an increasing trend, with forestry and plantation showing a steady increase. In contrast, agricultural exports from animal husbandry and fisheries show increasing volatility. Because of the serious environmental pollution problems in livestock farming and the relative lag in rural waste treatment technology, this may lead to more volatility in livestock agricultural export quality. For the fisheries industry, the lack of suitable species and the wide variation in water quality environments from one region to another create a challenge in breeding quality species. Meanwhile, Table 3 reports the results of the descriptive analyses of the variables in this article.

4 Analysis of regression results

4.1 Benchmark regression

In order to accurately examine the impact of e-commerce on the export quality of agricultural products in different regions of China,

5 where q_{iht} is the quantity of agricultural product h imported by country i in year t, p_{iht} is the price of agricultural product h imported by country i in year t, φ_h represents the fixed effect of agricultural product h, φ_{it} represents the joint country and year fixed effect, and ε_{hit} represents the residuals of agricultural product quality.

TABLE 1 Construction of e-commerce development level indicator system.

Category I indicators	Category II indicators	Meaning of the indicators	Causality	Weights
E-commerce preparedness	Investment in information fixed assets	Fixed-asset investment in information transmission, software and information technology services by region in China	Positive	0.0564
	Internet penetration	Ratio of Internet broadband access users to total population at the end of the year by region in China	Positive	0.0572
	telephone penetration	Ratio of mobile phone subscribers to total year-end population by region in China	Positive	0.0667
E-commerce usage	Size of e-commerce transactions	E-commerce sales by region in China	Positive	0.1331
	Express business volume	China's express delivery service by region	Positive	0.1537
	E-commerce practitioners	Number of employees in the e-commerce industry by region in China	Positive	0.1155
	Volume of telecommunication services	Total telecommunication business in China by region	Positive	0.0668
E-commerce impact	Contribution of e-commerce to GDP	Ratio of e-commerce turnover to GDP by region in China	Positive	0.0857
	B2B transactions as a share of consumption	Ratio of e-commerce sales to total consumer spending by region in China	Positive	0.0802
	Revenue from transport, warehousing and postal services	Total wages of persons employed in transport, storage and postal services in all regions of China	Positive	0.1848

The weights in the table are the average of the weights for each year.

this paper conducts a least-squares regression in accordance with model (1), with the export quality of agricultural products in each region of China at the HS6 position as the explanatory variable, and e-commerce in each province of China as the explanatory variable. The regression coefficients for e-commerce are significantly positive at the 1 per cent statistical level in column (1) of Table 4, controlling only for joint fixed effects at the level of year and product and at the level of region, product and destination country. The regression coefficients for e-commerce remain significant at the 1 per cent statistical level with the gradual addition of control variables at the regional level and at the level of the destination country in columns (2) and (3) of Table 4. Overall, using column (3) of Table 4, the faster the development of e-commerce, the higher the quality of agricultural exports, i.e., for every 1 per cent increase in e-commerce, the quality of agricultural exports improves by 6.5 per cent units, and Hypothesis 1 holds.

4.2 Robustness tests

This paper draws on existing studies to further demonstrate the robustness of e-commerce in improving the quality of agricultural exports. It conducts robustness tests from multiple perspectives: (1) Replacement of explanatory variables with explanatory variables. In this paper, the average price of the same agricultural product exported from each region of China to other destination markets is used as an instrumental variable for agricultural product price to re-measure the quality of agricultural product exports, and e-commerce significantly promotes the quality of agricultural product exports, as shown in column (1) of Table 5. Similarly, this finding remains robust when examining the lagged effects of e-commerce (column (2) of Table 5, Exhibit 2) and re-measuring the level of e-commerce using principal component analysis (column (3) of Table 5). (2) Other factors affecting e-commerce are taken into account, such as outlier fluctuations (Table 5, column (4)), industry unobservables (Table 5, column (5)), correlation of the error terms of the exporting countries (Table 5, column (6)) and sample-specific bias (Table 5, column (7)).[6] The results are consistent with the baseline regression after fully accounting for the above factors. (3) Considering the spillover effect of e-commerce, this paper measures the mean value of the proximity e-commerce level of provinces based on the spatial proximity matrix of 31 provinces in China, and this paper finds that e-commerce in proximity areas has a significant effect on the enhancement of the quality of agricultural products exported (column (8) of Table 5), which suggests that e-commerce has a robust spatial spillover effect.

4.3 Endogeneity test

Regions with higher-quality agricultural exports tend to attract more attention from international buyers, increasing local e-commerce transactions and activity and promoting e-commerce development. Thus, there is a reverse causality between e-commerce and agricultural export quality upgrading. In this paper, we address the above possible

6 According to the UNCOMTRADE database, Japan, Hong Kong, China, the United States, South Korea, Vietnam, Thailand, Malaysia, Germany, Indonesia, and Russia are the major countries or regions for China's agricultural exports. To eliminate the bias of specific samples, such as the above major agricultural exporting countries, in the regression results, the samples of the above countries are excluded from the robustness analysis in this paper.

TABLE 2 Classification of agricultural products.

Categorization	Product code (HS code)
Livestock raising	0101–0106, 0201–0210, 0401–0410, 0501–0511, 1,501–1,502, 1,505–1,506, 151,610, 152,190, 1,601–1,602, 2,301, 2,308, 2,309, 3,501–3,504, 4,101–4,104, 5,001–5,007, 5,101–5,007
Fisheries industry	0301–0307, 1,504, 0508, 05119, 1,603–1,605, 280,120, 7,101
Forest industry	0601–0602, 4,401–4,421, 4,501–4,504, 4,601–4,602, 4,701–4,707
Plantation	1,001–1,008, 1,101–1,109, 1,201–1,202, 1,209, 1,507–1,511, 151,620, 1,520–1,522, 1701–1704, 2,401–2,403, 5,201–5,203, 5,301–5,302, 551,030, 0701–0714, 06029010, 0603–0604, 2001–2007, 0803–0814, 200,820–200,890, 2009, 0801–0802, 0901, 0902, 0903, 1,204–1,208, 1,210–1,214, 1,211, 1801–1806, 2,101, 200,810, 0904–0910, 2,102–2,104, 220,900, 1901–1905, 2,105–2,106, 2,201–2,202, 2,203–2,208, 290,543, 290,544, 380,910, 1,301–1,302, 4,001, 3,301, 1,401–1,404, 2,302–2,307

endogeneity issues through an instrumental variables approach and screen instrumental variables from three perspectives: (1) Historical level instrumental variables (columns (1) and (2) of Table 6). Since the development of the Internet was based on the popularity of fixed-line telephones, historically, the higher the penetration rate of fixed-line telephones, the faster the level of e-commerce development. Meanwhile, before the popularization of telephones, people mainly exchanged information through paper mail, and the more post offices there were, the more frequent the information exchanges would be. Therefore, the number of fixed telephones and the number of post offices in each region of China at the historical level satisfy the requirement of instrumental variable correlation. In addition, the longer the history, the weaker the effect of the number of landline telephones and the number of post offices on the quality of today's agricultural exports, which fulfills the homogeneity requirement of the instrumental variables. Therefore, drawing on Nunn and Qian (2014), this paper uses the number of telephones per 100 people and the number of post offices per 10,000 people in each region of China in 1984 as instrumental variables for e-commerce, respectively. (2) Heteroskedastic instrumental variables (column (3) of Table 6). Suppose there is heteroskedasticity in the residuals from the regression of the endogenous explanatory variable on the exogenous variable. In that case, the cross-multiplication of that residual with the exogenous variable after removing the average trend can be used as a better instrumental variable (Lewbel, 2012). (3) Level of e-commerce in non-adjacent provinces (column (4) of Table 6). Since e-commerce is a clear plan made by China's Ministry of Commerce, the Central Internet Information Office, and the Development and Reform Commission in the whole country, this ensures that e-commerce in non-adjacent provinces is required as an instrumental variable for its relevance. At the same time, due to geographic, economic, and cultural differences, e-commerce in non-adjacent provinces cannot directly affect the development of e-commerce in their regions, which fulfills the exogenous requirement of the instrumental variable. Overall, the regression coefficients for e-commerce remain significant after addressing possible endogeneity issues, indicating the robustness of the benchmark regression results. Meanwhile, the validity of the instrumental variables all passed the corresponding tests.

4.4 Heterogeneity analysis

This paper analyses the regional, country, product, industry, and export levels to test whether there is heterogeneity in the quality enhancement of agricultural exports by e-commerce.

In terms of regional heterogeneity, e-commerce is more conducive to agricultural export quality upgrading in Eastern China and densely populated regions (columns (1)–(4) of Table 7), mainly considering that Eastern China has a larger market size and a more complete digital infrastructure, and farmers or enterprises can adjust their product structure more effectively through the demand information fed back from e-commerce platforms to achieve export quality upgrading. At the same time, abundant human capital supports farmers or enterprises in effectively utilizing e-commerce technology, further promoting the upgrading of agricultural exports.

In terms of country heterogeneity, the effect of e-commerce in promoting the quality of agricultural export products is more significant in LEP countries (columns (5) and (6) of Table 7). Considering that there are high information barriers to trade between LEP countries and other countries, the development of e-commerce can effectively reduce the cost of export information so that farmers or firms can adjust their production in a targeted manner to promote the improvement of agricultural product quality. The development of e-commerce can effectively cut the cost of export information so that farmers or enterprises can make targeted production adjustments and promote the quality of agricultural products.

In terms of product heterogeneity, based on Rauch (1999) classification, this paper classifies exported agricultural products into homogeneous and heterogeneous products. E-commerce has a more substantial facilitating effect on heterogeneous agricultural products, considering that differentiated products imply differentiated product preferences in the destination country's consumer market, and farmers or firms will continue to improve the quality of their export products to secure an export share in their niche market.

In terms of industry heterogeneity, e-commerce has a significant effect on the export quality of agricultural products in animal husbandry, forestry, and plantation, but not in the fishery (Table 7 (9)–(12)). The main reason is that fishery agricultural products depend highly on cold-chain logistics. In contrast, China's cold-chain logistics transport rate is only 30 percent, which is lagging behind and is not conducive to upgrading the quality of fishery agricultural exports.

About export heterogeneity, drawing on existing research, this paper decomposes agricultural exports into an intensive margin, an expansion margin, a geographic margin, and a quantitative margin (Hummels and Klenow, 2005; Arkolakis et al., 2008; Silva et al., 2014). The results of the analysis of export heterogeneity show that e-commerce promotes not only the intensive margin (increase in the number of agricultural exports) and the expansion margin (increase in the types of agricultural exports) but also the geographic margin (number of countries exporting agricultural

TABLE 3 Descriptive analysis.

	Variable	Variable names	Variable construction	Obs	Mean	Std. Dev.	Min	Max
Benchmark regression	*lnquality_distance*	Export product quality (instrumental variable is geographical distance)	Logarithmic value of product quality as measured by the residual method of demand (instrumental variable is the distance from each region of China to the export destination country)	1,607,750	0.459	0.1466	0	0.6931
	lnEC	Composite indicators for e-commerce (entropy approach)	The logarithmic value of comprehensive e-commerce indicators of Chinese regions measured by entropy weight method	1,608,421	0.2957	0.1674	0.031	0.6148
	lnArg_DEVT	Composite indicators for quality agricultural development(entropy approach)	The logarithmic values of agricultural high-quality development indicators in various regions of China as measured by the entropy weight method	1,608,421	1.1012	0.5542	0.0826	2.876
	lnOpen_proid	Openness of China's regions	The logarithmic value of the ratio of imports and exports to regional GDP by region in China	1,609,641	0.2613	0.2027	0.0102	0.81
	lnpergdp_proid	*Per capita* income levels by region in China	The logarithmic value of *per capita* income levels by region in China	1,609,641	10.5921	0.7703	8.654	11.9401
	lnOpen_country	Openness of the country	The logarithm of total exports and imports as a percentage of GDP for countries of destination of China's agricultural exports	1,589,671	0.5248	0.3138	0.0752	1.6599
	lnpergdp_country	National GDP *per capita*	The logarithmic value of *per capita* income levels of countries that are the destination of Chinese agricultural exports	1,609,641	11.2919	1.4079	6.8181	13.6311
	Belt	Belt and Road Dummy Variable	The dummy variable takes the value of 1 if the destination country of China's agricultural exports participated in the Belt and Road Initiative that year and 0 otherwise.	1,609,641	0.0363	0.187	0	1
Robustness analyses	*lnquality_price*	Export product quality (instrumental variable is product price)	The logarithmic value of product quality as measured by the residual demand method (the instrumental variable is the average price of the same product in each region of China to the market in the other destination country)	1,542,370	0.4515	0.1357	0	0.6931
	lnEC2	Composite e-commerce indicators (principal component analysis)	The logarithmic value of comprehensive e-commerce indicators measured by principal component analysis for each region in China	1,608,421	0.9096	0.3667	0.0998	1.5585
Endogenous analysis	*lnivwebmail_1984*	Number of post offices per 10,000 population, 1984	The logarithmic value of the number of post offices per 10,000 persons in each region of China in 1984	1,608,421	0.0648	0.0413	0.0045	0.1943
	lnivphone_1984	Number of telephones per 100 population, 1984	The logarithmic value of the number of telephones per 100 people in each region of China, 1984	1,608,421	0.0118	0.012	0.0006	0.0693
	lew	Heteroskedasticity instrumental variable	The product of the residuals from the regression of the endogenous variables on the exogenous variables with the centered exogenous variables	1,588,460	−0.0001	0.0079	−0.0323	0.0379
	lnEC_nonadjacent	Level of e-commerce in non-adjacent provinces	The logarithmic value of the mean of e-commerce levels in non-adjacent provinces in each region of China	1,608,421	0.1825	0.0084	0.1578	0.2001

(Continued)

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TABLE 3 (Continued)

	Variable	Variable names	Variable construction	Obs	Mean	Std. Dev.	Min	Max
Heterogeneity analysis	*size*	Expanding the margins	Types of agricultural products exported at HS6 position by region in China	1,499,216	1.1885	0.7799	1	26
	lnvalue	Intensive margin	The logarithmic value of HS 6-digit agricultural exports by region in China	1,608,931	11.955	2.6436	5.1098	17.886
	lngeo	Geographic margin	The logarithmic value of the number of HS 6-digit agricultural exporting countries by region in China	1,609,642	2.9386	1.0449	0.6931	4.8363
	lnquantity	Quantitative margin	The logarithmic value of the number of orders for agricultural products at the HS6 position by region in China	1,608,931	9.928	2.9375	1.3863	16.359
Mechanism analysis	*lnwei_service*	Servicification of agriculture	The logarithmic value of agricultural servitisation based on the OECD-ICIOD World Input–Output Database measured from the point of view of China's agricultural value added in exports	1,385,638	−4.9397	1.2476	−8.7297	−3.0528
	lnipd	Agricultural product preferences of destination countries	The logarithmic value of the degree of differentiation of agricultural products in destination countries	1,496,077	−1.1845	1.8333	−12.8714	4.585
Expansion analysis	*CEBC*	Cross-border e-commerce grouping variables	The dummy variable takes the value one if the firm's exports contain agricultural products under the CBEC list and 0 otherwise.	1,075,150	0.507	0.5	0	1
	CEBC_level	Degree of cross-border e-commerce	The logarithmic of the types of agricultural products exported by an enterprise that is on the CEBC list	1,075,150	0.4496	0.8327	0	4.9628

products) and the quantitative margin (number of orders for agricultural products) of agricultural products (columns in Table 7 (13)–(16)), suggesting that e-commerce not only reduces agricultural fixed and variable trade This suggests that e-commerce not only reduces fixed and variable trade costs of agricultural products but also helps farmers or enterprises to identify the market demand in the destination country and achieve market expansion and quality improvement.

4.5 Mechanism testing

Analysis of the theoretical mechanism reveals that, on the supply side, e-commerce promotes the Upgrading of the quality of agricultural exports through the modernization of the agricultural industry chain and supply chain (high-quality development of agriculture) and the enhancement of the level of agricultural services; on the demand side, e-commerce can accurately obtain information on the demand for agricultural products of the destination country, realize the expansion of the market for agricultural products and the matching of supply and demand, and promote the quality improvement of agricultural exports. Firstly, regarding the channel of modernization of the agricultural industry chain and supply chain, this paper constructs a comprehensive indicator of agricultural high-quality development (as shown in Exhibit 1) from four main perspectives: improvement of the quality and efficiency of agriculture, social contribution of agriculture, green development of agriculture, and innovation capacity of agriculture, to measure the modernization of the agricultural industry chain and supply chain. As shown in column (1) of Table 8, the coefficient of e-commerce is significantly positive, indicating that e-commerce promotes the high-quality development of agriculture and the modernization of the agricultural industry chain and supply chain. Secondly, regarding the agricultural servicing channel, this paper measures the level of agricultural servicing from the perspective of agricultural export value added based on the OECD-ICIOD World Input–Output Database. As shown in column (2) of Table 8, the coefficient of e-commerce is significantly positive, indicating that e-commerce enhances agricultural service. Finally, regarding the channel of preference for agricultural products in destination countries, we draw on Imbs and Wacziarg (2003), where we use the CEPII database to accurately measure the import preferences of global countries for China's HS6 agricultural products throughout 2000–2020, and use it to examine the channel of e-commerce's mechanism of choice for the destination country's market. As shown in column (3) of Table 8, the coefficient of e-commerce is significantly positive, which indicates that e-commerce can achieve the market expansion of agricultural products in the destination country and match supply and demand.

In addition, to examine the strength of the effect of e-commerce in promoting the quality improvement of agricultural exports under different mechanisms, this paper is grouped based on the median of the three mechanism variables mentioned above. It examines the differences in the effect of e-commerce on promoting the quality improvement of exports under different mechanism groups. Firstly, regarding the channels of agricultural industry chain and supply chain modernization, the coefficients of e-commerce in the group with high

TABLE 4 Benchmark regression.

Variables	(1)	(2)	(3)
	lnquality_distance		
lnEC	0.0772***	0.0639***	0.0650***
	(0.0242)	(0.0225)	(0.0226)
lnArg_DEVT		0.0102***	0.0107***
		(0.0028)	(0.0028)
lnOpen_proid		0.0421***	0.0442***
		(0.0101)	(0.0102)
lnpergdp_proid		0.0029	0.0019
		(0.0043)	(0.0043)
lnOpen_country			0.0178***
			(0.0027)
lnpergdp_country			0.0139***
			(0.0012)
Belt			0.0006
			(0.0006)
Year-Product	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes
Constant	0.4362***	0.3875***	0.2303***
	(0.0072)	(0.0455)	(0.0488)
Observations	1,606,547	1,606,547	1,586,660
R-squared	0.674	0.674	0.674

*, **, and *** respectively represent significance at the 10%, 5%, and 1% statistical levels. The values in parentheses represent the standard errors at the annual and provincial levels. The table shows that the statistical significance level and standard error are consistent without special explanation.

levels of agricultural industry chain and supply chain modernization are significant (columns (1) and (2) of Table 9), indicating that the modernization of the agricultural industry chain and supply chain is the primary channel for the improvement of the quality of agricultural products exports, and Hypothesis 2 is established. Second, regarding the agricultural servicing channel, the regression coefficients of e-commerce are significant in the high agricultural servicing level group (columns (3) and (4) of Table 9), indicating that agricultural servicing is the primary mechanism to improve the quality of agricultural exports. Based on this, this paper decomposes agricultural servicing according to the classification of productive service industries published by the National Bureau of Statistics of China in 2015. It examines the groups according to their median. The paper finds that e-commerce promotes agricultural export quality improvement through technology, transport and storage, information, finance, environmental protection, education, wholesale, and productive service activities (Exhibit 4), and Hypothesis 3 is valid. Finally, regarding the preference channels for agricultural products in destination countries, e-commerce is significant in both the low and high destination-country differentiation groups. The value is more important in the high destination country differentiation group (columns (5) and (6) of Table 9), which suggests that e-commerce can accurately obtain information on the demand for agricultural products in the destination countries, realize the expansion of agricultural products market and the matching of supply and demand, and promote the quality of agricultural products export, and Hypothesis 4 is established.

4.6 Extensibility analysis

This paper examines the causal effect of e-commerce on the improvement of agricultural export quality in various regions of China from a macro perspective in the benchmark regression. It is found that e-commerce can improve agricultural export quality through two main channels, namely, the modernization of the agricultural industry chain and supply chain, and the expansion of the agricultural market and the matching of supply and demand. In the extended analysis, this paper refines the research perspective to the micro-enterprise level, and examines the causal effect of e-commerce platform construction on the quality improvement of Chinese agricultural export enterprises using the double-difference approach. With regard to identifying the attributes of firms directly affected by e-commerce, this paper identifies firms exporting goods under the Cross-border E-commerce Retail Import Commodity List (CBEC List), jointly published by China's Ministry of Finance and other ministries, as firms likely to adopt cross-border e-commerce. The underlying logic of the grouping of CBEC firms is that if a firm's exports contain a commodity on the CBEC List, it is more affected by CBEC. This is compared to CBEC. This is compared to a country that does not export that commodity.

$$\begin{aligned} lnquality\_distance_{tikh} = {} & CBEC_i \times POST_t + lnOpen\_ \\ & proid_{tj} + lnpergdp\_proid_{tj} + \\ & lnOpen\_country_{tk} + lnpergdp\_ \\ & country_{tk} + Belt_{tkj} + \delta_{th} + \\ & \delta_{ihk} + \epsilon_{tikh} \end{aligned} \quad (14)$$

TABLE 5 Robustness tests.

	Re-measurement of the quality of products exported by enterprises	E-commerce lag	Principal component analysis to measure e-commerce	1 percent variable indentation
	(1)	(2)	(3)	(4)
Variables	*lnquality_distance*			
lnEC	0.0557**	0.0395**	0.0240***	0.0634***
	(0.0248)	(0.0168)	(0.0059)	(0.0225)
Controls	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes
Constant	0.1686***	0.2426***	0.2605***	0.2287***
	(0.0428)	(0.0476)	(0.0482)	(0.0490)
Observations	1,525,995	976,259	1,586,660	1,586,660
R-squared	0.682	0.689	0.674	0.674
	Increased fixed effects at the industry level	Misadjustment of clustering criteria	Excluding specific samples	Spatial spillover effects of e-commerce
	(5)	(6)	(7)	(8)
Variables	*lnquality_distance*			
lnEC	0.0646***	0.0650***	0.0640***	0.0240***
	(0.0226)	(0.0056)	(0.0065)	(0.0083)
Controls	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes
Constant	0.2317***	0.2303***	0.2447***	0.2288***
	(0.0488)	(0.0224)	(0.0254)	(0.0526)
Observations	1,564,824	1,586,660	1,118,165	1,528,741
R-squared	0.673	0.674	0.694	0.672

*, **, and *** respectively represent significance at the 10%, 5%, and 1% statistical levels. The values in parentheses represent the standard errors at the annual and provincial levels. The table shows that the statistical significance level and standard error are consistent without special explanation.

TABLE 6 Endogeneity analysis.

	Number of post offices per 10,000 population, 1984	Number of telephones per 100 population, 1984	Heteroskedasticity instrumental variable	Level of e-commerce in non-adjacent provinces
	(1)	(2)	(3)	(4)
Variables	*lnquality_distance*			
lnEC	0.5219***	0.4620***	0.0264***	0.4385***
	(0.0448)	(0.0185)	(0.0074)	(0.0252)
Controls	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes
Observations	1,457,961	1,457,961	1,457,961	1,437,057
R-squared	−0.007	−0.005	0.001	−0.004
Kleibergen-Paap rk LM statistic	1.5e+04 0.000	9.0e+04 0.000	1.2e+05 0.000	4.8e+04 0.000
Cragg-Donald Wald F statistic	1.3e+04 0.000	8.0e+04 0.000	49.761 0.000	4.1e+04 0.004

*, **, and *** respectively represent significance at the 10%, 5%, and 1% statistical levels. The values in parentheses represent the standard errors at the annual and provincial levels. The table shows that the statistical significance level and standard error are consistent without special explanation.

TABLE 7 Heterogeneity analysis.

	Geographic location		Size of population		Economic levels		Product differences	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	*lnquality_distance*							
lnEC	0.0719	0.0508**	0.0573	0.0578**	0.0987***	0.0212	0.0462**	0.0520**
	(0.0444)	(0.0240)	(0.0386)	(0.0239)	(0.0294)	(0.0216)	(0.0213)	(0.0229)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.6059***	0.0310	0.3860***	0.3448***	0.2100***	0.5659***	0.0799	0.3317***
	(0.0956)	(0.0687)	(0.0849)	(0.0708)	(0.0557)	(0.1065)	(0.0492)	(0.0578)
Observations	364,753	1,221,907	434,363	1,152,297	1,095,803	490,857	638,888	617,109
R-squared	0.731	0.666	0.719	0.678	0.692	0.801	0.720	0.653
χ^2 *statistic*	18.84		37.23		77.84		3.13	
	0.0000		0.0000		0.0000		0.0771	
	Livestock raising	Fisheries industry	Forest industry	Plantation	Expanding the margins	Intensive margin	Geographic margin	Quantitative margin
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Variables	*lnquality_distance*							
lnEC	0.1041***	−0.0339	0.1206***	0.0438*	0.3656***	1.0701**	0.6365**	1.4654***
	(0.0355)	(0.0342)	(0.0313)	(0.0245)	(0.0877)	(0.4289)	(0.2926)	(0.4561)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.1304	−0.4074***	0.3362***	0.2413***	−0.0061	1.5425*	1.4241***	−0.6911
	(0.0920)	(0.1185)	(0.0651)	(0.0513)	(0.1800)	(0.7973)	(0.3830)	(0.8822)
Observations	79,365	68,804	513,335	719,065	1,479,181	1,587,761	1,588,460	1,587,761
R-squared	0.754	0.733	0.632	0.690	0.753	0.760	0.948	0.789

*The original hypothesis in columns (1) and (2) of Table 7 is that there is no systematic difference in the quality of e-commerce for agricultural exports from the eastern region and the non-eastern region; columns (3) and (4) are that there is no systematic difference in the quality of e-commerce for agricultural exports from the low-population-size group and the high-population-size group; columns (5) and (6) are that there is no systematic difference in the quality of e-commerce for agricultural exports from low- and high-economically-developed countries; and columns (7, 8) are that there is no systematic difference in the quality of e-commerce for agricultural exports from the homogenous and the heterogeneous regions.

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TABLE 8 E-commerce impact mechanism test.

	High-quality agricultural development	Servicification of agriculture	Agricultural product preferences of destination countries
	(1)	(2)	(3)
Variables	*lnArg_DEVT*	*lnwei_service*	*lnipd*
lnEC	**0.2872*** **	**0.0247***	**0.1156*** **
	(0.0940)	**(0.0129)**	**(0.0397)**
Controls	**Yes**	**Yes**	**Yes**
Year-Product	**Yes**	**Yes**	**Yes**
Proids-Products-Destinations	**Yes**	**Yes**	**Yes**
Constant	**−0.1975**	**−0.0154**	**0.2675****
	(0.1631)	**(0.0173)**	**(0.1165)**
Observations	**1,588,460**	**1,379,593**	**1,476,183**
R-squared	**0.910**	**0.969**	**0.926**

*, **, and *** respectively represent significance at the 10%, 5%, and 1% statistical levels. The values in parentheses represent the standard errors at the annual and provincial levels. The table shows that the statistical significance level and standard error are consistent without special explanation.

TABLE 9 Test of channel mechanism under e-commerce perspective.

	(1)	(2)	(3)	(4)	(5)	(6)
	Agricultural Chain and Modernization Low Group	Agricultural Chain and Modernization High Group	Low level of servitization in agriculture	High level of servitization in agriculture	Low preference group for agricultural products in destination countries	High preference group for agricultural products in destination countries
Variables	*lnquality_distance*					
lnEC	−0.0249	0.0727***	0.0371	0.0687**	0.0525**	0.0674***
	(0.0503)	(0.0224)	(0.0243)	(0.0277)	(0.0243)	(0.0242)
lnwei_service			0.0049	0.0171		
			(0.0111)	(0.0267)		
lnipd					0.0106***	0.0041***
					(0.0007)	(0.0004)
Arg_DEVT	0.0040	0.0134***	0.0075**	0.0149***	0.0036	0.0096***
	(0.0037)	(0.0042)	(0.0032)	(0.0039)	(0.0033)	(0.0025)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes	Yes	Yes
Proids-Products-Destinations	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.3999***	0.0889	0.0179	0.4186***	0.3107***	0.2198***
	(0.0913)	(0.0674)	(0.0860)	(0.1275)	(0.0571)	(0.0529)
Observations	513,686	1,072,974	504,334	861,643	565,360	909,227
R-squared	0.741	0.698	0.757	0.644	0.762	0.721
χ2	88.27		9.11		3.86	
statistic	0.0000		0.0025		0.0495	

*The original hypothesis in columns (1) and (2) of Table 9 is that there is no systematic difference in the quality of e-commerce for agricultural exports in the low versus the high agricultural chain and supply chain groups; in columns (3) and (4) it is hypothesized that there is no systematic difference in the quality of e-commerce for agricultural exports in the low versus the high service level subgroups; and in columns (5) and (6) it is hypothesized that there is no systematic difference in the quality of e-commerce for agricultural exports in the low versus the high destination country differentiated group.

The model set in the extended analysis is shown in Equation (14). $lnquality\_distance_{tikh}$ represents agricultural export quality; $CBEC_i$ denotes cross-border e-commerce grouping. If the enterprise's export products contain agricultural products under the CBEC list, the value of the dummy variable $CBEC_i$ will be 1, otherwise it will be 0; $POST_t$ denotes the time-shock dummy variable, and since China Customs

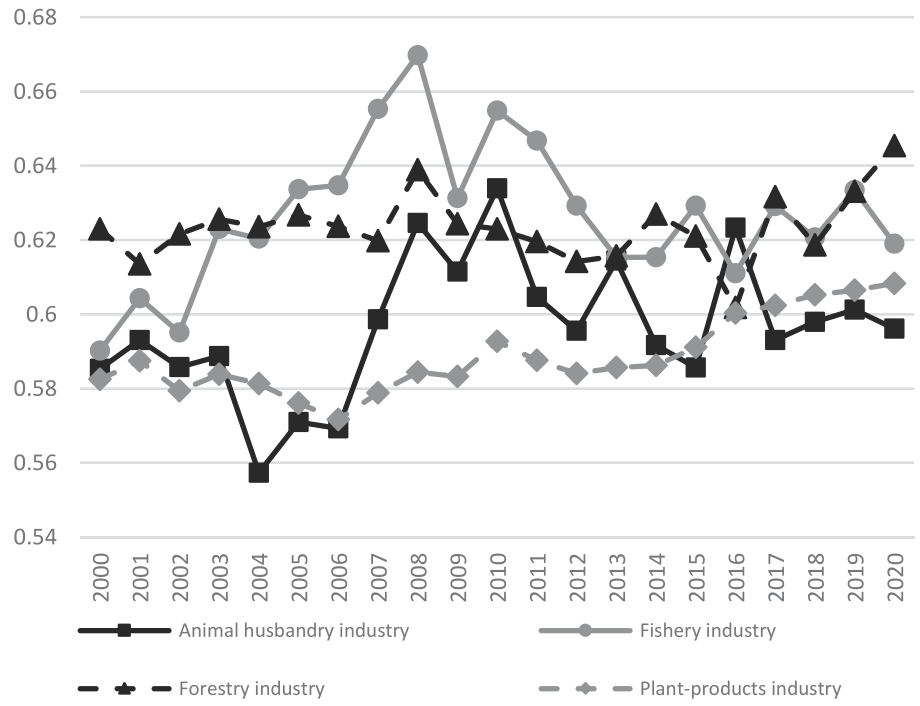

FIGURE 1
Distribution of export product quality.

TABLE 10 Impact of cross-border e-commerce on the quality of enterprises' agricultural exports.

	Distance tool variables	Average price instrumental variables	Degree of cross-border e-commerce	Worker-enterprise matching data
	(1)	(2)	(3)	(4)
Variables	*lnquality_distance*	*lnquality_price*	*lnquality_distance*	*lnquality_distance*
CBEC_POST	0.0020***	0.0026***		0.0057**
	(0.0007)	(0.0009)		(0.0026)
CBEC_level _POST			0.0030***	
			(0.0006)	
Controls	Yes	Yes	Yes	Yes
Year-Product	Yes	Yes	Yes	Yes
Firms -Products-Destinations	Yes	Yes	Yes	Yes
Constant	0.3034***	0.4082***	0.3040***	−0.1972
	(0.0532)	(0.0701)	(0.0531)	(0.1963)
Observations	1,066,720	817,652	1,066,720	148,888
R-squared	0.899	0.863	0.899	0.921

*Clustering criteria are misadjusted to the firm level.

desensitized firms' information after 2016, the time frame of the data in the extended analysis is limited to 2009–2016. In addition, China's Ministry of Finance and other departments have published more than 10 policy documents on cross-border e-commerce since 2012, and the corresponding cross-border e-commerce service pilot zones have been established one after another since 2012, so this paper defines 2012 as the year of policy implementation, i.e., the time-difference dummy variable (Post) takes the value of 1 in the period of 2012–2016, and the time-difference dummy variable (Post) takes the value of 0 in the period of 2009–2011; and the rest of the control variables are consistent with those of the baseline regression. δ_{th} denotes joint year and product fixed effects; δ_{jhk} denotes joint fixed effects of Chinese exporting firms, products and destination countries; and ϵ_{tikh} is a random perturbation term.

The regression results are shown in column (1) of Table 10. The regression coefficient of cross-border e-commerce is significant at the

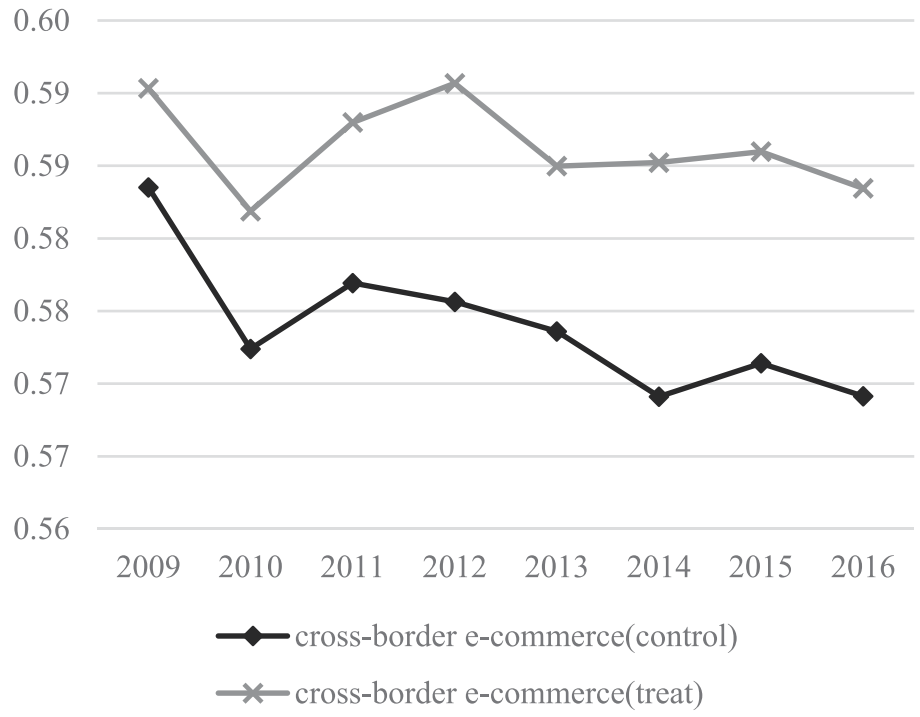

FIGURE 2
Parallel trend chart.

1% statistical level, indicating that the construction of cross-border electronic commerce platforms has a significant contributing effect on agricultural export enhancement. Consistent with the robustness analysis, this paper uses the average price of agricultural products exported by enterprises to other markets. This is done to re-measure the quality of enterprises' export products. Its results are shown in column (2) of Table 10. In addition, this paper uses the cross-border e-commerce level (CBEC_level) to reconstruct the interaction term for the regression, and the regression results are shown in column (3) of Table 10. Finally, considering China as a traditional manufacturing country, it has a unique advantage in processing agricultural products. In addition, processed agricultural products have a higher value-added technology content than primary products. In this paper, the regression test is re-conducted by matching the Chinese customs data with the Chinese industrial enterprise database. The database. The regression coefficient of cross-border e-commerce is significant at 5% in column (4) of Table 10.

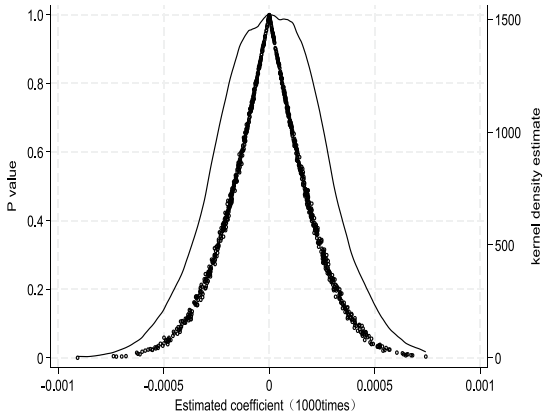

FIGURE 3
Placebo test chart.

In this paper, we check the accuracy of double-difference regression results from two perspectives: the parallel trend test and the placebo test. (1) Parallel trend test. The parallel trend test is necessary to determine whether the double-difference method effectively identifies causal effects. Since the counterfactual of the treatment group after the policy shock cannot be directly observed, whether the change trend after the policy shock is the same is judged by whether the treatment group and the control group have the same change trend before the policy shock (Jacobson et al., 1993, p. 685). As shown in Figure 2, before 2012, the quality of agricultural exports of the treatment group and the control group maintained the same trend of change, while after 2012, the treatment group and the control group experienced significant fluctuations, and the magnitude of the change in the quality of agricultural exports of the enterprises adopting cross-border e-commerce was higher than that of the enterprises that did not adopt international -border e-commerce. (2) Placebo test. Placing a placebo test involves constructing a virtual treatment group or virtual policy shock time to test if the regression results are affected by other policy factors or random factors (Li et al., 2016, p. 18). Specifically, this paper randomly generates the same number of firms according to cross-border e-commerce firms. Then it is regressed again with the $POST_t$ time dummy variable to construct the interaction term. Repeat the above process 1,000 times to get the coefficients, standard errors and p-values of 1,000 regressions. Figure 3

shows the p-value density distribution of 1,000 regressions of "pseudo" cross-border e-commerce policies on the quality of enterprises' agricultural exports, and it can be seen that the coefficients of the randomly generated "pseudo" cross-border e-commerce policies are mainly distributed in the vicinity of 0, and far away from the double-differential regression coefficients (regression results in column (1) of Table 9); most of the p-values are far away from the 5% significance level, which indicates that the results of double differencing are not by chance, but are caused by cross-border e-commerce policies.

4.7 Analysis results

Our findings indicate that e-commerce development has a significant contribution to the improvement of agricultural export quality in all regions of China, and the effect persists after a series of robustness tests. In addition, e-commerce has long-term and spatial spillover effects on agricultural export quality improvement. We also found that e-commerce has a stronger promotional effect in eastern China, where the population size is larger. Additionally, e-commerce bridges the digital divide in low-developed countries, demonstrating export heterogeneity. Our experience also confirms that the quality enhancement of agricultural exports by e-commerce is mainly achieved through two channels: the high-quality development of the agricultural industry chain and supply chain, and the matching of information on agricultural products demand in the consumer markets of destination countries. Finally, we find that China's 2012 cross-border e-commerce policy can effectively promote agricultural exports through the double-difference method.

5 Discussion

Firstly, in terms of research perspectives, we further examine the impact of e-commerce development on the quality of China's agricultural exports on top of Zhou et al. (2023) study. Although the implementation of cross-border e-commerce policies has promoted the quality of China's agricultural exports as a whole, given the differences in the degree of economic development of different regions in China, this paper needs to explore further how e-commerce has contributed to the reasons for the upgrading of the quality of agricultural exports in the other areas of China. Given this, this paper broadens the research perspective from the country to China's regions, which, to a certain extent, bridges the gap of existing research. The study results show that e-commerce significantly contributes to improving the quality of agricultural exports in different regions of China. This effect is more pronounced in eastern China and areas with larger populations. Secondly, regarding research methodology, the existing literature on e-commerce commonly adopts double-difference models for causal identification (Cao et al., 2021; Han et al., 2023). Due to the uneven degree of economic development in different regions of China, analyzing the growth of e-commerce only from the policy implementation perspective is prone to ignore the uniqueness and differences in the development of e-commerce in different regions, which may interfere with the regression results. In this paper, 10 sub-indicators measuring the degree of e-commerce development in the Chinese areas are screened from the three aspects of e-commerce readiness, e-commerce use, and e-commerce influence, and the weights are assigned based on the idea of information entropy to construct a comprehensive development index of e-commerce for each region in China. After making the broad indicators of e-commerce, this paper further adopts a high-dimensional fixed-effects model to study the impact of e-commerce on the quality of agricultural exports, which can identify the role of e-commerce more accurately, improve the accuracy of the results of the study, and provide a more scientific basis for the implementation of e-commerce policy in developing countries such as China. Finally, regarding the impact mechanism, this paper finds that e-commerce promotes the quality of agricultural exports at the supply level by modernizing the agricultural industry chain and supply chain and servicing. Meanwhile, e-commerce enables agricultural export quality upgrading at the demand level through the channel of agricultural product preference in the destination country. Although it has been argued that e-commerce realizes the reverse integration of the agricultural industry chain and supply chain through the construction of a demand-led production model, a service-led organizational model, and an emerging value creation model, which promotes the development of agricultural products on a large scale, industrialized and of high quality (Montealegre et al., 2007; Wasihun and Maumbe, 2013; Tao et al., 2021), but these findings lack the support of empirical results. Therefore, this paper empirically analyses the above mechanisms through a mediated effects model to test the effectiveness of the transmission mechanism.

While this paper extends the study data to 2020, given the direct impact of today's global economic uncertainty on agricultural trade, future research will expand the sample to further examine how e-commerce can help countries cope with global economic uncertainty.

Based on the establishment of the global unified open market platform of e-commerce, it will break the information barriers and entry barriers of the overseas market of agricultural products, and realize the expansion of agricultural products' intensive margins and expansion margins. On this basis, with the help of the e-commerce platform, we can further explore the information on the demand for agricultural products in different destination countries, and adjust the export structure of agricultural products according to the demand information, optimize the market layout, and upgrade the quality of agricultural products exported. In addition, countries around the world, especially those with a lower level of economic development, need to actively participate in the construction of a global unified market platform for e-commerce, which is crucial to reducing the cost of agricultural trade, realizing the modernization of agriculture, and building a strong country in agricultural trade.

6 Conclusion

This paper calculates the export quality of agricultural products at the HS6 level for each region in China. It uses Chinese customs data from 2000 to 2020. Subsequently, comprehensive e-commerce indicators were constructed from e-commerce readiness, e-commerce usage and e-commerce influence in combination with the China Statistical Yearbook and the China E-Commerce Report published by the Ministry of Commerce of China for the years 2000–2020. On this basis, a high-dimensional fixed-effect model is used to study the causal effect of e-commerce on agricultural export quality. In addition,

this paper also explores the impact of cross-border e-commerce policies on the quality of agricultural products of Chinese exporters using the double-difference method. The findings provide substantial support for the upgrading of e-commerce on the quality of Chinese agricultural exports.

This paper finds: First, e-commerce has a significant facilitating effect on agricultural export quality improvement in all regions of China. Second, the promotion effect is more significant in eastern China. This is because of regions with larger population sizes, importers with lower economic development, and heterogeneous products. Third, there exists industry heterogeneity in the quality improvement of agricultural exports through e-commerce. This is mainly manifested in the animal husbandry, forestry and plantation industries, while the promotion effect on fisheries is not noticeable. Forth, e-commerce has heterogeneous effects on agricultural exports, which can be seen in the intensive margin, expanding margin, geographical margin, and margin of agricultural exports. Fifth, the improvement of agricultural export quality by e-commerce is mainly realized through the channels of high-quality development of the agricultural industry chain and supply chain and the docking channels of agricultural demand information from the consumer market in the destination countries. Among them, in the high-quality development channel of the agricultural industry chain and supply chain, e-commerce can integrate agricultural science and technology, transport and storage, information, finance, environmental protection, education, wholesale and production service support and other service activities from the level of productive services, realize the transformation and upgrading of agriculture, and promote the enhancement of the quality of agricultural products exports. Sixth, from the perspective of microenterprises, cross-border e-commerce policies can significantly promote agricultural product quality upgrading by Chinese export enterprises.

In this paper, we suggest the following countermeasures: first, develop a strong digital infrastructure. E-commerce development cannot be separated from digitized data, cloud computing, artificial intelligence and the Internet and other digital technologies. China needs to further increase digital infrastructure construction and improve digital technology. Second, promote the use of digital information and digital technology in the field of agricultural production, build a farm-based e-commerce platform, link up all the links in the upstream, midstream and downstream of the agricultural industry chain supply chain, and realize the sharing of national information, the sharing of technology, the building of brands, and the traceability of quality problems, so as to ensure the quality of the supply of agricultural products. Third, promote the establishment of cross-border e-commerce platforms to expand agricultural consumer information from the consumer side to the production side, and achieve intelligent manufacturing and personalized customization of agricultural products. Fourth, improve laws and regulations related to e-commerce, focus on long-term e-commerce mechanisms, ensure e-commerce security and trust, and enhance e-commerce's long-term, substantive, and internationalization. Fifth, strengthen international cooperation on global digital trade rules for agricultural products and promote the establishment of common digital trade rules for agricultural products. Actively participate in the exchanges and co-operation between the United States, Europe and other developed agricultural countries on the rules of digital trade in agricultural products, exchange views on the formulation of rules of digital trade in agricultural products, digital information flow and product quality traceability, and form global rules of digital trade in agricultural products at an early date to satisfy their respective demands.

Against the backdrop of the rapid development of the digital economy, e-commerce has become a meaningful way to upgrade the quality of developing countries' exports. However, due to the timeliness of China's customs data release, the data used in this study are only updated to 2020, which may overlook the impact of changes in the international market environment on the quality of developing countries' agricultural exports in recent years. In addition, as the quality of agricultural exports from developing countries continues to improve, the gains from agricultural export trade are gradually increasing, which leads to the fact that the traditional trade allocation method is no longer applicable. Unfortunately, this paper does not explore in depth how to build a fairer and more equitable agricultural trade distribution mechanism in the context of e-commerce, especially to achieve a reasonable distribution of value among consumers, e-commerce platforms, and producers, which is undoubtedly a direction for further exploration in future research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JLi: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. JS: Writing – original draft. RC: Data curation, Writing – review & editing. JW: Writing – review & editing. JLiu: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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