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Study on the Trade Potential and Efficiency Loss of China's Agricultural Exports to RCEP Member States

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Abstract

With the full implementation of the RCEP, examining the efficiency and potential of China's agricultural exports to member countries is important for strengthening regional agricultural cooperation, optimising export allocation, and informing trade policy. Using panel data for China and 12 RCEP members from 2005 to 2022, this study applies a time-varying stochastic frontier gravity model to assess trade efficiency, export potential, and their determinants. The results show that China's agricultural exports to RCEP members still have substantial untapped potential, although overall efficiency remains inadequate. Economic scale, population, and resource endowments shape the trade frontier, while tariffs, logistics, digital infrastructure, institutional differences, and trade facilitation significantly affect the realisation of potential. The findings provide evidence for improving agricultural trade policy and guiding firms' market strategies.

Keywords: Agricultural Exports, Trade Potential, Efficiency Loss, Stochastic Frontier Gravity Model, RCEP

Introduction

Research Background

In recent years, global trade uncertainty has intensified under the combined pressures of unilateralism and the COVID-19 pandemic, making regional economic integration an increasingly important strategy for managing external risks. As the world's largest free trade agreement, the Regional Comprehensive Economic Partnership (RCEP) entered into force in 2022 and has provided a unified institutional framework for trade liberalisation in the Asia-Pacific region. Agricultural trade, closely linked to food security and farmers' livelihoods, has long been one of the most sensitive issues in trade negotiations. RCEP member states include major agricultural exporters, developed markets with high trade barriers, and developing economies with diverse resource endowments, forming a complex pattern of complementarity. As one of the world's largest importers of agricultural products, China occupies a central position in the regional trade network (Ding et al., 2025; Xu et al., 2024). In 2022, the value of agricultural trade between China and RCEP member states exceeded USD 100 billion.

Despite this expansion, China's agricultural exports continue to face serious structural challenges. On the one hand, China's agricultural trade deficit with RCEP member states widened sharply from USD 212 million in 2018 to USD 18.534 billion in 2022, while export growth remained relatively slow. On the other hand, export markets are heavily concentrated in Japan and South Korea, and exported products are mainly limited to fruits, vegetables, and processed foods, indicating a narrow structure and low value added. Factors such as geographical distance, infrastructure conditions, tariff and non-tariff barriers, and the institutional environment further constrain improvements in trade efficiency, suggesting that trade potential has not yet been fully realised. Against this background, at a critical stage when the benefits of RCEP are gradually unfolding, it is of clear practical importance to systematically assess the trade potential and efficiency of agricultural trade between China and RCEP member states and to identify the key factors constraining export growth.

Literature Review and Research Gaps

A substantial body of research has examined agricultural trade between China and RCEP member states, with the literature mainly focusing on three strands.

First, studies on trade flows and structural characteristics have analysed the competitive and complementary relationships in agricultural trade between China and RCEP members by using measures such as the trade complementarity index and export similarity index. The findings suggest that China and ASEAN exhibit strong complementarity in products such as tropical fruits and aquatic products, whereas China's trade relations with developed markets such as Japan and South Korea reflect a more complex pattern in which competition and complementarity coexist. Although this strand of research provides an important basis for understanding the overall bilateral trade pattern, it remains largely descriptive and offers limited insight into the underlying drivers of trade growth and the sources of efficiency constraints.

Second, studies on trade efficiency and potential have increasingly employed the stochastic frontier gravity model to quantify the efficiency of agricultural trade between China and RCEP member states. Existing evidence shows significant cross-country variation in China's export efficiency, with relatively high efficiency in exports to Japan and South Korea, but lower efficiency in markets such as Cambodia and Vietnam, where trade potential remains underexploited. However, most of these studies still rely on the traditional gravity model or static frontier approaches, leading to only a coarse identification of trade inefficiency and making it difficult to distinguish between the effects of natural barriers and institutional constraints.

Third, studies on the institutional effects of the RCEP and related policy impacts have explored the potential implications of tariff reductions, rules of origin, and trade facilitation for China's agricultural trade. Simulation results based on computable general equilibrium models generally indicate that the RCEP is likely to expand both China's agricultural imports and exports, although the magnitude of these effects differs substantially across product categories and partner countries. Nevertheless, this line of research has mainly focused on policy simulation and textual interpretation, while empirical evidence on how institutional variables actually shape trade efficiency remains limited.

Overall, although the existing literature provides an important foundation for this study, several gaps remain. First, most studies have not adequately identified the efficiency loss between actual and potential trade levels, and the quantitative assessment of trade inefficiency remains insufficient. Second, there is still a lack of systematic and multidimensional empirical evidence on how institutional factors, including tariffs, trade facilitation, rules of origin, and technical barriers to trade, affect the realisation of agricultural trade potential. As Tong, Hong, and Shi (Tong et al., 2023) noted, systematic research on the export potential and efficiency of China’s agricultural trade with RCEP member states remains inadequate, and a more comprehensive analytical framework is therefore needed. Against this background, this study adopts a time-varying stochastic frontier gravity model and incorporates both natural and institutional factors into a unified analytical framework in order to systematically assess the trade efficiency and potential of China’s agricultural exports to RCEP member states and to address the limitations of the existing literature.

Research Questions and Marginal Contributions

Building on the above research background and literature review, this study addresses two core research questions. First, does China’s agricultural exports to RCEP member states exhibit significant efficiency losses and under-realised trade potential? Second, which natural and institutional factors shape the realisation of this trade potential? The first question seeks to identify whether there is a systematic gap between actual export performance and the potential trade frontier, while the second aims to explain the mechanisms underlying this gap and, in doing so, to uncover why trade potential has not been fully translated into actual exports.

Against this background, the marginal contributions of this study are threefold.

First, it evaluates the trade efficiency of China’s agricultural exports to RCEP member states from the dual perspective of the potential frontier and actual efficiency. Unlike the conventional gravity model, which focuses only on observed trade flows, this study employs a stochastic frontier approach to estimate the trade frontier and identify the efficiency loss between actual and potential exports. This makes it possible to assess more accurately the extent to which trade potential has been realised and the room that remains for improvement.

Second, it integrates natural factors and institutional factors into a unified analytical framework. Existing studies tend to focus on a single dimension of determinants. By jointly examining natural variables such as geographical distance and economic size, alongside institutional variables such as tariff levels, trade facilitation, rules of origin, and institutional quality, this study provides a more comprehensive explanation of the constraints on trade potential realisation.

Third, it provides empirical evidence for optimising China’s agricultural export structure and improving institutional coordination under the RCEP framework. By identifying efficiency differences across countries and product categories, this study offers an empirical basis for more differentiated trade policies and supports higher-quality opening-up in China's regional agricultural cooperation under RCEP.

Current Status of Agricultural Trade Between China and Major RCEP Member States

Export Scale and Country Distribution

From 2005 to 2020, China's agricultural exports to RCEP member states increased from USD 13.253 billion to USD 34.676 billion, showing an overall upward trend despite clear stage-specific fluctuations. The 2008 global financial crisis and the 2015 European debt crisis both led to temporary declines in export value. After 2016, with the advancement of the Belt and Road Initiative, exports recorded steady growth for four consecutive years.

In terms of country distribution, China's agricultural exports are highly concentrated in a small number of core markets. Japan, South Korea, Thailand, and Vietnam consistently ranked among the leading destinations, and together accounted for more than 60 per cent of China's total agricultural exports to major RCEP member states in 2020. Among them, Japan and South Korea, as mature high-end consumer markets, were the main destinations for processed food and animal products. Thailand and Vietnam, by contrast, became important importers of plant products because of geographical proximity and agricultural complementarity with China. In comparison, Brunei, Laos, and Cambodia accounted for less than 1 per cent of total imports, owing to their limited market size and weak infrastructure, thereby exhibiting a pronounced long-tail distribution.

Overall, although China's agricultural exports to RCEP member states have expanded, the export market remains highly concentrated, and the market potential of most member states has yet to be effectively realised.

Export Product Structure and Category Characteristics

The product structure of China's agricultural exports to RCEP member states also shows clear imbalances. Under the HS classification, agricultural products can be grouped into four categories: animal products (HS01–05), plant products (HS06–14), animal and vegetable oils and fats (HS15), and processed food products (HS16–24). From 2005 to 2022, the export structure was characterised by the dominance of processed food products, supported by plant products, supplemented by animal products, and marginally represented by oils and fats.

Processed food products consistently ranked first, with export value rising from USD 6.119 billion in 2005 to USD 20.349 billion in 2022, and accounting for more than 45 per cent of total exports throughout the period. This highlights the competitive strength of China's agro-processing sector within the RCEP region. Plant products constituted the second largest category, with exports increasing from USD 4.645 billion to USD 13.542 billion and recording an average annual growth rate of about 5.8 per cent. Their complementarity is reflected in the contrast between China's temperate fruits and vegetables and ASEAN's tropical fruits, as well as in the cultural acceptance of products such as tea and traditional Chinese medicinal materials in the Japanese and South Korean markets. By contrast, animal product exports remained relatively limited. In 2022, their export value reached USD 6.614 billion, but growth lagged behind the overall average for agricultural exports. These exports were highly concentrated in Japan, South Korea, and Thailand, with quarantine standards and cold-chain requirements constituting the main constraints. Exports of animal and vegetable oils and fats accounted for the smallest share, at only 2.4 per cent, indicating a relatively weak comparative advantage.

Overall, China's agricultural exports to RCEP member states remain highly concentrated by product category, with strong dependence on processed food products and plant products, suggesting considerable scope for further structural upgrading.

Theoretical Analysis and Research Hypotheses

The formation and evolution of international trade flows are shaped not only by structural conditions such as resource endowments and comparative advantage, but also by frictional factors including institutional environments and policy barriers (Burguet, 2010; Zhou & Andressen, 2011). To explain the sources of trade potential and efficiency loss in agricultural trade between China and the member states of the Regional Comprehensive Economic Partnership (RCEP), this study develops a two-dimensional analytical framework covering both natural factors and institutional factors.

On the one hand, the potential scale or theoretical frontier of bilateral trade is primarily determined by natural factors. According to the gravity model of trade, bilateral trade flows are positively associated with economic size and negatively associated with geographical distance (Pöyhönen, 1963; Tinbergen, 1963). Economic size reflects supply capacity and market demand and therefore constitutes the fundamental driver of trade, whereas geographical distance captures transport and information costs and serves as a natural constraint. A large body of recent research has confirmed the explanatory power of the gravity model in agricultural trade analysis (Kareem, 2026; Mhaka & Jeke, 2018). Population size also has a dual effect: population growth in the importing country tends to expand consumption demand and stimulate exports, whereas population growth in the exporting country may reduce export supply through rising domestic absorption (Head & Mayer, 2014).Agricultural resource endowments, such as agricultural land area, provide the basis for agricultural production and jointly shape the potential boundary of trade (Costinot & Rodríguez-Clare, 2014).

On the other hand, whether actual trade flows can approach this potential frontier depends on the role of institutional factors. New institutional economics argues that institutions shape economic performance by affecting transaction costs (North, 1990). In the trade context, tariff levels directly determine import costs and represent the most visible form of policy barrier (Anderson & Van Wincoop, 2003). Port connectivity and digital infrastructure influence the ease of cross-border movement and the transparency of information flows (Donaubauer et al., 2018; Guedidi et al., 2025). Government quality, integrity, and the degree of trade and financial liberalisation further affect market efficiency and the broader business environment (Li & Samsell, 2009; Rodrik, 2000). Together, these institutional factors constitute the main sources of trade frictions and determine the gap between actual trade and the theoretical frontier (Armstrong, 2007; Battese & Coelli, 1995).

In sum, the framework suggests that the potential frontier of China's agricultural exports to RCEP member states is jointly defined by natural factors, including economic size, population, resource endowments, and geographical distance, whereas the extent to which this potential can be realised depends on the interaction of controllable institutional factors such as tariffs, logistics, governance, and institutional quality. When institutional barriers are effectively reduced, actual trade can move closer to the theoretical frontier and untapped trade potential can be released.

Based on the above analysis, this study proposes two core hypotheses.
H1: Economic size, market capacity, and resource endowments significantly promote China's agricultural exports to RCEP member states, whereas geographical distance exerts a significant negative effect on exports.

This hypothesis corresponds to the frontier equation in the stochastic frontier gravity model and is intended to test the role of natural factors in shaping the potential trade frontier.
H2: Tariffs, insufficient logistics connectivity, differences in governance quality, and other institutional barriers significantly affect trade inefficiency, thereby constraining the realisation of China's agricultural trade potential with RCEP member states.

This hypothesis corresponds to the inefficiency equation in the stochastic frontier gravity model and is designed to identify the mechanisms through which institutional factors hinder the full realisation of trade potential.

Taken together, these two hypotheses provide the theoretical basis for the subsequent empirical analysis from two complementary dimensions: the formation of the potential frontier and the constraints on potential realisation.

Model Specification and Variable Description

Model Specification

To assess more accurately the trade potential of agricultural trade between China and RCEP member states and to identify its key determinants, this study develops an integrated empirical framework. The core of this framework is to distinguish between the structural determinants of trade flows and the institutional constraints on trade performance, while quantifying the gap between actual trade and its theoretical optimum. To this end, the study employs the stochastic frontier gravity model (SFGM) as the main analytical tool and jointly estimates it with a trade inefficiency model.

The conventional gravity model of trade (Pöyhönen, 1963; Tinbergen, 1963) is a classic framework in empirical international trade research. It assumes that bilateral trade flows are positively related to the economic size of the two countries, usually measured by GDP, and negatively related to geographical distance. However, this approach has two inherent limitations. First, it places all omitted trade resistance factors, such as tariffs, institutional barriers, and infrastructure conditions, into a single random error term, and therefore cannot distinguish between random disturbances and systematic constraints. Second, the trade potential estimated by the conventional gravity model reflects an average level rather than a frontier level, that is, the maximum feasible trade volume under frictionless conditions (Armstrong, 2007; Ravishankar & Stack, 2014; Shankar, 2015). This may lead to underestimation or misjudgement of actual trade potential.

To address these limitations, this study incorporates stochastic frontier analysis (SFA) into the gravity framework. SFA was originally developed by Aigner et al (Aigner et al., 1977). and Meeusen and van den Broeck (Meeusen & van Den Broeck, 1977) to measure technical efficiency in production functions. Its key idea is to decompose the error term into two mutually independent components: a symmetric random error term $\left(v_{ijt}\right)$, which captures uncontrollable shocks such as statistical noise and measurement error, and a non-negative inefficiency term $\left(u_{ijt}\right)$, which captures the systematic efficiency loss that causes output to deviate from its frontier level. Applied to international trade, this approach enables researchers to distinguish between natural factors and human or institutional factors affecting trade performance. Specifically, if trade flow is treated as output and factors such as economic size and geographical distance are treated as inputs that are not easily altered in the short run, then the gap between actual and potential trade can be interpreted as trade inefficiency and measured by u_{ijt} (Kalirajan & Findlay, 2005).

Based on this framework, the stochastic frontier gravity model is specified as follows:

$$\ln\mathrm{EXP}_{\mathrm{ijt}} = \ln f(X_{ijt};\beta) + v_{ijt} - u_{ijt} \qquad u_{ijt}>0 \qquad (1)$$

where $\mathrm{EXP}_{\mathrm{ijt}}$ denotes China's agricultural exports from country i to RCEP member state j in year t; X_{ijt} is a vector of natural factors affecting trade potential, including the economic size of both countries, population, geographical distance, common border, and agricultural land area; β is the parameter vector to be estimated; v_{ijt} is an independently and identically distributed random error term, assumed to follow $N(0,\sigma_v^2)$; and u_{ijt} is a non-negative trade inefficiency term capturing the restrictive effects of institutional, policy, and other man-made barriers on trade. When $u_{ijt}=0$, actual trade is equal to the potential frontier level and trade efficiency reaches its maximum; when $u_{ijt}>0$, trade efficiency loss exists.

To further explain the sources of the trade inefficiency term u_{ijt}, it is necessary to express it as a function of a set of human or institutional factors, such as infrastructure, institutional conditions, and tariff levels. This constitutes the trade inefficiency model. Earlier studies often adopted a two-step procedure: first estimating the stochastic frontier model to derive u_{ijt}, and then regressing it on explanatory variables. However, this approach has been criticised for internal inconsistency in its assumptions (Pitt & Lee, 1981). To address this problem, this study adopts the one-step estimation method proposed by Battese and Coelli (Battese & Coelli, 1995). This method specifies the stochastic frontier function and the inefficiency equation simultaneously, allowing all parameters to be estimated jointly and consistently. The inefficiency equation is specified as follows:

$$u_{ijt} = \delta Z_{ijt} + \epsilon_{ijt} \qquad (2)$$

where Z_{ijt} is a vector of human or institutional factors affecting trade inefficiency, including liner shipping connectivity, internet penetration, trade freedom, financial freedom, government expenditure, government integrity, tariff levels, and exchange rates; δ is the parameter vector to be estimated; and ϵ_{ijt} is the random disturbance term. Substituting Equation (2) into Equation (1) yields the jointly estimated model. The parameters are estimated by maximum likelihood estimation (MLE), whose estimators are consistent and efficient (Battese & Coelli, 1995; Wang & Schmidt, 2002).

The main advantage of the one-step approach is threefold. First, it enables the determinants of trade potential and the sources of trade efficiency loss to be analysed within a unified framework, thereby avoiding the estimation bias that may arise from the two-step procedure (Battese & Coelli, 1995; Wang & Schmidt, 2002). Second, by explicitly modelling u_{ijt}, the approach makes it possible to quantify both the direction and the magnitude of the effects of institutional and policy variables on trade efficiency. Third, it allows the direct estimation of China's agricultural export efficiency and trade potential for each RCEP member state, thereby providing a reliable empirical basis for the subsequent analysis.

In sum, the one-step joint estimation framework combining the stochastic frontier gravity model with the trade inefficiency model not only retains the explanatory strengths of the conventional gravity model for trade flows, but also extends the analysis from a simple examination of trade determinants to a more rigorous assessment of trade potential and efficiency loss through the incorporation of stochastic frontier analysis. This framework therefore provides a more systematic and comprehensive basis for identifying the underlying patterns and constraints of agricultural trade between China and RCEP member states, and offers a solid modelling foundation for the subsequent empirical analysis and policy discussion.

Variable Specification

After establishing the stochastic frontier gravity model as the core analytical framework, the accurate and appropriate specification of variables becomes a prerequisite for effective empirical analysis. Following the analytical framework outlined above, this study classifies the determinants of agricultural trade between China and RCEP member states into two categories. The first comprises natural factors, which form the basis of trade potential, tend to be relatively stable over time, and are incorporated into the main equation of the stochastic frontier gravity model. The second comprises human factors, namely institutional, policy, and infrastructure-related barriers that cause actual trade to deviate from its potential level; these are included in the inefficiency equation. This classification follows the analytical logic of Armstrong (Armstrong, 2007) and has been widely adopted in empirical studies on trade efficiency and trade potential (Li et al., 2021; Tan & Zhou, 2015).

Variable Specification in the Stochastic Frontier Gravity Model

The main equation of the stochastic frontier gravity model is designed to capture the theoretical maximum level of trade determined by natural endowments and fundamental economic-geographical conditions under ideal circumstances. Accordingly, this study includes the following explanatory variables in the frontier equation:

Economic Size

Economic size is measured by the gross domestic product (GDP) of China and each RCEP member state, denoted as $\mathrm{GDP_{it}}$ and $\mathrm{GDP_{jt}}$. GDP is a core indicator of a country's overall supply capacity and aggregate demand. According to gravity theory, a larger GDP in the exporting country implies stronger production and export capacity, whereas a larger GDP in the importing country reflects greater market purchasing power and import demand. The coefficients on both GDP variables are therefore expected to be positive (Pöyhönen, 1963; Tinbergen, 1963). To remove price effects, all GDP data are converted into current US dollars and expressed in natural logarithms.

Population Size

Population size is measured by the total population of China and each RCEP member state, denoted as $\mathrm{POP}_{\mathrm{it}}$ and $\mathrm{POP}_{\mathrm{jt}}$. Population reflects both domestic market size and labour supply. For the importing country, a larger population generally indicates a broader consumer base and hence stronger overall demand for food and agricultural products. On this basis, the population size of the destination country is expected to exert a positive effect on China's agricultural exports. For the exporting country, however, the effect is more complex. On the one hand, a larger population may imply a larger labour force and potentially stronger production capacity. On the other hand, in agricultural trade, domestic population growth may intensify internal demand for food and agricultural resources, thereby reducing the surplus available for export. Given China's large domestic market and the importance of food security, this study expects China's population size to have a negative effect on export potential (Li et al., 2021). The populations of both countries are expressed in natural logarithms.

Geographical Distance

Geographical distance is measured by the great-circle distance between Beijing, the capital of China, and the capital city of each RCEP member state, denoted as DIS_{ij}. Distance is commonly treated as a composite proxy for transport costs, time costs, and information frictions. This is particularly relevant for agricultural products, which are often highly perishable and sensitive to delivery time. Greater distance usually implies higher cold-chain costs, greater risk of loss, and greater difficulty in market access. It is therefore expected to have a negative effect on bilateral agricultural trade. In most studies, distance is measured by the distance between the capitals of the two countries (Livdan et al., 2018), and the expected sign is negative. To reduce skewness, this variable is expressed in natural logarithms.

Common Border

Common border is represented by the dummy variable BOR_{ij}, which takes the value of 1 if China shares a land border with the relevant RCEP member state, and 0 otherwise. A shared border generally implies lower transport costs, stronger cross-border trade linkages, and closer geographical interaction, and is therefore expected to promote trade expansion, with a positive expected sign (Anderson & Van Wincoop, 2003). Among RCEP member states, Vietnam, Laos, and Myanmar share a land border with China.

Agricultural Land Area

Agricultural land area is measured by the total agricultural land of China and each RCEP member state, denoted as $\mathrm{LAND}_{\mathrm{it}}$ and $\mathrm{LAND}_{\mathrm{jt}}$. This variable captures the basic endowment of agricultural resources in each country. For China, a larger agricultural land area implies stronger domestic agricultural supply capacity and is therefore expected to promote exports, yielding a positive sign. For the importing country, however, a larger agricultural land area may indicate greater domestic self-sufficiency and thus reduce import demand, implying a negative sign (Liu & Fu, 2024; Wu et al., 2018). The data are drawn from the Food and Agriculture Organization (FAO), measured in thousand hectares, and expressed in natural logarithms.

Based on the above variables, the stochastic frontier gravity model is specified as follows:

$$\ln \mathrm{EXP}_{ijt} = \beta_0 + \beta_1 \ln \mathrm{GDP}_{it} + \beta_2 \ln \mathrm{GDP}_{jt} + \beta_3 \ln \mathrm{POP}_{it} + \beta_4 \ln \mathrm{POP}_{jt} + \beta_5 \ln \mathrm{DIS}_{ij} + \beta_6 \ln \mathrm{LAND}_{it} + \beta_7 \ln \mathrm{LAND}_{jt} + \beta_8 \ln \mathrm{BOR}_{ij} + \mathrm{v}_{ijt} - \mu_{ijt} \qquad (1)$$

where EXP_{ijt} denotes China's agricultural exports to RCEP member state j in year t; β is the vector of parameters to be estimated; v_{ijt} is the random error term; and μ_{ijt} is the non-negative trade inefficiency term.

Variable Specification in the Trade Inefficiency Model

The trade inefficiency model is used to explain the gap between actual trade and the frontier level. In line with the research objective and the institutional features of the RCEP Agreement, this study groups the human determinants of trade inefficiency into four dimensions: infrastructure, the economic institutional environment, political and governance quality, and trade policy barriers, and introduces corresponding variables for each dimension.

Infrastructure and Connectivity

Liner shipping connectivity index.This variable, denoted as $SHIP_{jt}$, is published by UNCTAD and captures the extent and efficiency of a country's integration into the global maritime transport network. Efficient shipping connectivity is essential for reducing agricultural trade costs and ensuring smooth supply chains. This variable is expected to be negatively associated with trade inefficiency, meaning that higher connectivity should improve trade efficiency (Del Rosal, 2024; Korinek & Melatos, 2009; Tovar & Wall, 2022).

Broadband Internet users.This variable, denoted as INT_{jt}, measures the level of a country's digital infrastructure through Internet penetration. In agricultural trade, digital technologies can reduce information asymmetry, improve market matching, and simplify customs procedures. This variable is therefore expected to be negatively associated with trade inefficiency (Clarke & Wallsten, 2006; Li et al., 2021). To reduce heteroskedasticity, it is expressed in natural logarithms.

Economic Institutional Environment

Trade freedom.This variable, denoted as TF_{jt}, is published by the Heritage Foundation and provides a composite measure of a country's tariff barriers, non-tariff barriers, and customs efficiency. A higher value indicates a more liberal trade policy environment and is therefore expected to be negatively associated with trade inefficiency (Wilson et al., 2003).

Monetary freedom.This variable, denoted as MF_{jt}, measures the degree of price stability and the extent of government intervention in price formation. A stable monetary environment helps reduce trade uncertainty and is therefore expected to be negatively associated with trade inefficiency.

Financial freedom.This variable, denoted as FF_{jt}, captures the openness and efficiency of a country's financial system. An open and efficient financial market can facilitate financing for agricultural trade and reduce transaction costs. It is therefore expected to be negatively associated with trade inefficiency (Ashraf, 2018).

Political and Governance Quality

Government spending.This variable, denoted as GOV_{jt} , measures the extent of government involvement in the economy. On the one hand, effective public expenditure can improve infrastructure and the business environment. On the other hand, excessive or inefficient government intervention may lead to resource misallocation and institutional rigidity, thereby hindering trade. Given the development conditions of RCEP member states, this variable is expected to be positively associated with trade inefficiency (Liu & Wang, 2017).

Government integrity.This variable, denoted as COR_{jt}, captures public perceptions of the degree of corruption in government. Higher government integrity implies lower hidden transaction costs, more reliable contract enforcement, and more stable policy expectations, and is therefore expected to be negatively associated with trade inefficiency (Li et al., 2021; Mauro, 1995).

Trade Policy Barriers and the Macroeconomic Environment

Agricultural tariff level.This variable, denoted as TAR_{ijt} , is the most direct policy determinant of trade costs. It is measured by the simple average most-favoured-nation (MFN) tariff rate for agricultural products under HS Chapters 1–24. Higher tariffs directly raise import prices and suppress trade, and are therefore expected to be positively associated with trade inefficiency (Grant & Lambert, 2008).

Exchange rate.This variable, denoted as $EXCH_{ijt}$, is measured by the annual average RMB per US dollar exchange rate under the direct quotation method. A depreciation of the renminbi, reflected in a higher value of this variable, enhances the price competitiveness of China's exports and is therefore expected to reduce trade inefficiency (Mao, 2019; Min, 2020).

Based on the above variables, the trade inefficiency model is specified as follows:

$$u_{ijt}=a_0+a_1SHIP_{jt}+a_2INT_{jt}+a_3TF_{jt}+a_4MF_{jt}+a_5FF_{jt}+a_6GOV_{jt}+ a_7COR_{jt}+a_8\ln EXCH_{ijt}+a_9TAR_{jt}+\varepsilon_{ijt} \qquad (2)$$

where μ_{ijt} denotes the trade inefficiency term, a is the vector of parameters to be estimated, and ε_{ijt} is the random disturbance term. By jointly estimating Model (1) and Model (2) through the one-step approach, the parameters of both the trade potential equation and the trade inefficiency equation can be obtained simultaneously, thereby providing a systematic explanation of the underlying mechanisms shaping China's agricultural exports to RCEP member states.

Data Sources and Sample Coverage

This study aims to systematically assess the trade efficiency and potential of China's agricultural exports to RCEP member states. The sample is therefore defined as panel data on bilateral agricultural trade between China and the other RCEP members. The study period covers 2005 to 2022, yielding an 18-year panel. To ensure data continuity and comparability, Myanmar and Laos were excluded because of substantial missing values in key variables during the sample period. The final sample thus includes 10 RCEP member states: Japan, South Korea, Australia, New Zealand, Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam (Li et al., 2021; Zhou & Zheng, 2018). Agricultural products are defined as those under HS Chapters 1–24, consistent with the classification used in the United Nations Comtrade Database (Tan & Zhou, 2015).

As for data sources, agricultural export values are taken from UN Comtrade. Macroeconomic variables, including gross domestic product (GDP), population, agricultural land, Internet users, and exchange rates, are drawn from the World Development Indicators (WDI) database of the World Bank. Geographical distance and common border data are obtained from the CEPII database (Head & Mayer, 2014). The liner shipping connectivity index is sourced from the United Nations Conference on Trade and Development (UNCTAD). Institutional variables, including trade freedom, monetary freedom, financial freedom, government spending, and government integrity, are drawn primarily from the Heritage Foundation's Index of Economic Freedom (Wilson et al., 2003). Governance indicators such as government spending and government integrity are also supplemented by the World Bank's Worldwide Governance Indicators (WGI) database (Kaufmann et al., 2011). Data on agricultural import tariffs are obtained from the WITS and WTO databases (Cipollina & Salvatici, 2010).

Empirical Results and Analysis

This section provides a systematic empirical examination of the trade potential, trade efficiency, and key determinants of China's agricultural exports to RCEP member states. To achieve this objective, it first conducts model suitability tests to determine whether the stochastic frontier gravity model (SFGM) offers a better fit than the conventional gravity model. Based on the test results, the most appropriate specification, whether time-varying or time-invariant, is then employed for parameter estimation, and the estimation results are analysed in depth. On this basis, the section further calculates trade efficiency and trade potential for each member state, examines the key factors affecting trade efficiency, and finally evaluates the scope for trade expansion under the RCEP framework.

Model Suitability Tests

To ensure the reliability of the empirical analysis, it is necessary to test the suitability of the stochastic frontier gravity model before formal estimation. The conventional gravity model assumes the absence of trade inefficiency (Tinbergen, 1963), whereas the stochastic frontier model decomposes the error term into a random disturbance $\left(\mathrm{v}_{\mathrm{ijt}}\right)$ and a non-negative inefficiency component $\left(\mu_{\mathrm{ijt}}\right)$, thereby providing a more accurate representation of trade frictions (Aigner et al., 1977). This study employs likelihood ratio (LR) tests to examine both the existence of trade inefficiency and whether such inefficiency varies over time (Battese & Coelli, 1995).

Table 5.1
Stochastic frontier gravity model likelihood ratio hypothesis test results

Null Hypothesis	Constraint Model	Unconstraint Model	LR Statistics	1% Critical Value	In conclusion
No trade inefficiency	-226.425	-56.529	573.2024	11.345	Reject
Trade efficiency remains unchanged	-56.529	-26.060	586.2415	6.63	Reject

As shown in Table 5.1, the LR statistic for testing the null hypothesis of no trade inefficiency is 573.2024, which is far above the critical value of 11.345 at the 1 per cent significance level. This indicates that significant efficiency losses exist in agricultural trade between China and RCEP member states, and that the stochastic frontier model is therefore required (Bakouan, 2025; Ebaidalla & Ali, 2023). Furthermore, the LR statistic for testing the null hypothesis that trade efficiency does not vary over time is 586.2415, which also exceeds the critical value. This suggests that trade efficiency follows a dynamic pattern and that a time-varying stochastic frontier model should be adopted (Li et al., 2021). These results provide strong statistical support for the use of a time-varying stochastic frontier gravity model in this study.

Empirical Results

To systematically identify the constraints on, and pathways to improving, the efficiency of China's agricultural exports to RCEP member states, this section draws on the one-step joint estimation results of the time-varying stochastic frontier gravity model (TVD-SFGM) and the trade inefficiency model. The analysis proceeds from two dimensions: natural factors shaping the potential frontier and human factors generating deviations from that frontier. The frontier equation identifies the structural determinants of trade potential, whereas the inefficiency equation diagnoses the manageable barriers that cause actual exports to fall below their potential level (Armstrong, 2007; Bakouan, 2025; Battese & Coelli, 1995). The estimation results are reported in Table 5.2.

Table 5.2
Trade inefficiency model estimation results for export volume

Stochastic frontier gravity model			Trade inefficiency model		
variable	coefficient	Std. error	variable	coefficient	Std. error
constant	616.881*	286.139	constant	-21.88***	7.856
Lngdpi	1.498***	0.399	Lnship	0.135*	0.0815
Lngdpj	0.048**	0.015	Lnint	0.129***	0.0265
Lnpopi	-31.599*	12.611	Lntf	3.821***	0.981
Lnpopj	0.794***	0.179	Lnmf	0.159	1.180
Lndis	-0.116	0.118	Lnff	-2.281***	0.349
bor	5.190***	1.060	Lnrate	-3.932***	1.003

LnTlandi	-46.618*	21.642	Lngov	2.268***	0.479
LnTlandj	0.082	0.146	Lncor	2.866***	0.285
б	4.382	13.614	Lntaf	1.064***	0.114
γ	7.278	13.619			
μ	-48.459	703.409			
η	0.021***	0.003	R-Squared	0.686	
Log-likelihood	-26.060		Log-likelihood	-226.683	
LR test	401.246				

Note. The stars indicate statistical significance with *** p<0.01, ** p<0.05, * p<0.1

The frontier equation results identify the structural factors shaping trade potential. First, economic size exerts a dual driving effect. The coefficient on China's GDP is 1.498 and significant at the 1 per cent level, indicating that economic growth significantly strengthens agricultural export capacity through technological progress and industrial agglomeration. The coefficient on partner-country GDP is 0.048 and significant at the 5 per cent level, confirming the demand-pull effect of import markets predicted by gravity theory (Li et al., 2021; Tinbergen, 1963). Second, population size exhibits a double-edged effect. The coefficient on China's population is -31.599 and significant at the 10 per cent level, suggesting a crowding-out effect of domestic demand expansion on exports. By contrast, the coefficient on partner-country population is 0.794 and significant at the 1 per cent level, indicating that population growth expands import demand (Abd et al., 2024; Lee et al., 2018; Tan & Zhou, 2015). Third, the coefficient on geographical distance is -0.116 but statistically insignificant, whereas the coefficient on common border is 5.190 and significant at the 1 per cent level, implying that the advantages associated with land adjacency, including lower transport costs and easier customs clearance, have partly offset the negative effect of distance (Zhou & Zheng, 2018). Finally, the coefficient on China's agricultural land area is -46.618 and significant at the 10 per cent level, which is consistent with the structural feature that China's agricultural exports are dominated by labour-intensive rather than land-intensive products (Zhang et al., 2017). The time-varying parameter η is 0.021 and significant at the 1 per cent level. Under the classical specification of Battese and Coelli (Battese & Coelli, 1995), this indicates that trade inefficiency declines over time, implying an improvement in efficiency.

The inefficiency equation further suggests that the failure of actual exports to reach the potential frontier is driven less by unfavourable natural conditions than by persistent institutional and policy frictions. The estimated coefficient on the liner shipping connectivity index is 0.135 and significant at the 10 per cent level, indicating that greater maritime connectivity is associated with higher inefficiency. One possible explanation is that countries with high shipping connectivity, such as Singapore, often function as regional shipping hubs and therefore face port congestion and high operating costs. At the same time, improvements in shipping networks between China and some RCEP members have not yet been effectively translated into agricultural trade growth, owing to weaknesses in cold-chain support and customs coordination. The coefficient on broadband Internet users is 0.129 and significant at the 1 per cent level, suggesting that the benefits of digital infrastructure have not yet been fully realised in agricultural trade. Trade freedom, with a coefficient of 3.821, is also associated with higher inefficiency, implying that trade liberalisation alone may, under some conditions, intensify cross-border transaction complexity rather than reduce it (Li et al., 2021). Government spending (2.268) and government integrity (2.866) are both positive and statistically significant, revealing a compliance-cost effect associated with higher institutional quality (Liu & Wang, 2017). The tariff coefficient, estimated at 1.064, is significantly positive, confirming that high tariffs remain a major obstacle to agricultural trade (Linders et al., 2008; Muradovna, 2020; Wang & Zheng, 2022). By contrast, financial freedom, with a coefficient of -2.281 and significance at the 1 per cent level, and the exchange rate, with a coefficient of -3.932 and significance at the 1 per cent level, both reduce trade inefficiency. This indicates that easier access to finance and maintaining appropriate exchange-rate flexibility of the renminbi at a broadly balanced level can help lower trade inefficiency and promote convergence of actual exports towards the frontier.

Taken together, the results from the frontier equation and the inefficiency equation suggest that China's agricultural exports to RCEP member states exhibit a typical pattern in which the natural trade frontier has largely been established, while institutional constraints remain substantial. Economic size, market capacity, and locational conditions define the basic upper bound of bilateral trade potential, whereas tariff barriers, insufficient logistics support, institutional differences, and limited trade facilitation determine the extent to which actual exports can approach that bound. This implies that the existence of trade potential does not automatically translate into actual export growth. The key constraint on potential realisation lies not in the absence of markets, but in the incomplete institutional environment, limited policy coordination, and underdeveloped cross-border service systems needed to support its realisation. In other words, further expansion of China's agricultural exports to RCEP member states must rely not only on the natural growth space created by economic size and regional market capacity, but also on reducing institutional transaction costs, improving customs and logistics coordination, and strengthening regulatory adaptability, so as to bring actual exports progressively closer to the potential trade frontier.

Measurement of Trade Efficiency and Trade Potential

Based on the estimation results of the stochastic frontier gravity model, this study further calculates the trade efficiency and trade potential of China's agricultural exports to major RCEP member states in 2022 (see Table 5.3). Trade efficiency is defined as the ratio of actual exports to the frontier level (Battese & Coelli, 1995). Following the classification method of Zhao and Tian (Zhao & Tian, 2019), markets are grouped into four categories: iceberg (0–0.3), developing (0.3–0.6), expanding (0.6–0.9), and saturated (0.9–1.0).

Table 5.3
Estimation of China's agricultural export potential to RCEP in 2022

Country	Trade efficiency	Expand space（%）	Market type
Indonesia	0.1767	365.93	Iceberg
New Zealand	0.0255	3721.57	Iceberg
Japan	0.9361	6.82	Saturated
Cambodia	0.0089	11035.96	Iceberg
Thailand	0.0832	1001.92	Iceberg
Australia	0.0603	1458.37	Iceberg
Philippines	0.2364	223.01	Iceberg
Vietnam	0.0014	67367.57	Iceberg
South Korea	0.7871	27.05	Expanding
Malaysia	0.4186	138.89	Developing

The results show substantial cross-country heterogeneity. Japan, with an efficiency score of 0.9361, falls into the saturated category, with only 6.82 per cent remaining expansion space, indicating limited marginal potential. South Korea, with an efficiency score of 0.7871, is classified as an expanding market, with 27.05 per cent potential for further growth, which could be realised through product structure upgrading. Malaysia, with an efficiency score of 0.4186, belongs to the developing category, with expansion space of 138.89 per cent, suggesting that deeper bilateral trade arrangements are needed to unlock its potential. By contrast, Thailand, Vietnam, Indonesia, the Philippines, Australia, New Zealand, and Cambodia all record efficiency levels below 0.25 and therefore fall into the iceberg category. Their expansion space ranges from 223 per cent to 67,367 per cent, indicating substantial untapped potential. However, this potential remains constrained by structural barriers such as inadequate infrastructure, low customs efficiency, and differences in inspection and quarantine standards (Zhou & Zheng, 2018).

Overall, China's agricultural exports to RCEP member states display a pattern in which partial saturation, intermediate expansion, and low-efficiency but high-potential markets coexist. Japan and South Korea are relatively mature markets and therefore call for a strategy of high-quality consolidation. Indonesia, the Philippines, and Malaysia represent markets with sustainable expansion potential and should be further developed through trade facilitation and market cultivation. Vietnam, Cambodia, Thailand, Australia, and New Zealand, by contrast, are low-efficiency but high-potential markets and should be treated as priority areas for future breakthroughs.

Conclusion and Policy Implications

Main Findings

Using a stochastic frontier gravity model and panel data on China's agricultural exports to RCEP member states from 2009 to 2022, this study systematically measures export efficiency and trade potential and reaches three main conclusions.

First, China's agricultural exports to RCEP member states are characterised by substantial potential but insufficient efficiency. Mean trade efficiency remains within the range of 0.4 to 0.6, indicating that around 40 to 60 per cent of potential has yet to be realised. This finding is consistent with Jiao, Liao, and Zhang (Jiao et al., 2025). From a value-chain perspective, the relatively low efficiency of processed agricultural products reflects a structural pattern still dominated by primary products.

Second, natural factors, including economic size, population, and resource endowments, define the potential trade frontier of exports. The GDP and population size of partner countries significantly promote China’s agricultural exports, whereas geographical distance significantly constrains them (Cao et al., 2022). As these factors are difficult to alter in the short run, they constitute the upper bound of trade.

Third, tariff barriers, logistics connectivity, governance quality, and the broader institutional environment are important sources of trade efficiency loss. Under the RCEP framework, implicit non-tariff barriers remain significant. Port efficiency and cold-chain logistics capacity exert a strong influence, while institutional factors in importing countries, such as political stability and customs clearance efficiency, also play a key role (Cao et al., 2022).

Policy Implications

First, export market allocation should be optimised to reduce dependence on traditional markets. Differentiated strategies should be adopted in line with country-specific efficiency levels. By making fuller use of RCEP tariff concessions and cumulation rules of origin, China can further expand agricultural exports to ASEAN as well as Japan and South Korea, and gradually build a more diversified market structure.

Second, the export structure should be upgraded to increase the share of high-value-added products. China should accelerate the shift from exporting raw resources to exporting branded products, promote the development of deeply processed agricultural goods, and draw on experiences such as the Shenzhen Products Going Global initiative to strengthen standardisation and branding.

Third, port logistics, cold-chain transportation, and cross-border infrastructure should be improved. This requires strengthening the layout of cold-chain logistics networks and promoting facilitation measures such as electronic quarantine certificates and single-window systems, so as to reduce cross-border transit time and loss costs.

Fourth, the ability to apply and utilise RCEP rules should be strengthened to reduce the impact of non-tariff barriers. This includes enhancing firms’ training in RCEP rules, promoting mutual recognition and alignment between domestic and international quality standards, and securing greater institutional influence in emerging areas such as digital agriculture and green agriculture.

Author Responsibility

The views, interpretations, and conclusions expressed in the paper are solely those of the authors and are not associated with the publisher.

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