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Research Article

Tariff Concessions, SPS Barriers and Agricultural Trade Efficiency Between China and Vietnam: Evidence from Multi-product Stochastic Frontier Gravity Model

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Abstract

Against the backdrop of deepening RCEP regional economic integration and continuous upgrading of China-Vietnam bilateral economic and trade cooperation, agricultural trade, as a core component of cross-border commodity trade between the two countries, plays a vital role in optimizing bilateral trade structures and promoting regional industrial complementarity. In recent years, continuous tariff concession policies have significantly reduced the tariff cost threshold for China-Vietnam agricultural trade, while sanitary and phytosanitary (SPS) barriers, as typical non-tariff trade barriers, have gradually become the core restrictive factor affecting bilateral agricultural trade flows and efficiency. Existing studies mostly adopt traditional gravity models to analyze the linear correlation between trade policies and trade volume, lacking targeted efficiency measurement and heterogeneous mechanism analysis of multi-category agricultural products. Based on panel data of 28 subdivided agricultural product categories traded between China and Vietnam from 2015 to 2024, this study constructs a multi-product stochastic frontier gravity model to measure the overall efficiency and loss level of bilateral agricultural trade, and systematically explores the differential impact of tariff concessions and SPS barriers on agricultural trade efficiency. Further, this paper conducts heterogeneous subsample tests based on product attributes including primary agricultural products, processed agricultural products, and tropical characteristic agricultural products. The empirical results show that tariff concessions significantly improve China-Vietnam agricultural trade efficiency and reduce trade inefficiency loss, while SPS barriers produce prominent inhibitory effects on trade efficiency; the two factors present significant interactive offset effects in bilateral agricultural trade. Heterogeneous test results indicate that primary agricultural products are most sensitive to SPS barrier restrictions, processed agricultural products benefit the most from tariff concession dividends, and tropical characteristic agricultural products have the lowest overall trade efficiency due to dual constraints of high compliance costs and strict technical standards. Regional economic cooperation mechanisms, border infrastructure construction and institutional trade openness can significantly alleviate trade efficiency losses caused by SPS barriers and amplify the positive effect of tariff concessions. This study clarifies the hierarchical influence mechanism and heterogeneous action logic of tariff and non-tariff barriers on China-Vietnam agricultural trade efficiency, fills the research gap of multi-product differentiated empirical analysis in bilateral agricultural trade research, and provides empirical evidence and targeted policy references for optimizing China-Vietnam agricultural trade layout, breaking through technical trade barriers, and improving bilateral agricultural trade facilitation and efficiency under the RCEP framework.

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Keywords

China-Vietnam Agricultural Trade, Tariff Concessions, SPS Barriers, Trade Efficiency, Stochastic Frontier Gravity Model, Heterogeneous Test, RCEP

1. Introduction

1.1. Research Background

As important neighboring economies and core participating countries of the RCEP agreement, China and Vietnam have maintained rapid growth in bilateral trade scale and increasingly close industrial and economic ties in the past decade. Agricultural trade, supported by superior geographical proximity, resource endowment complementarity and industrial matching characteristics, has always been a key field of bilateral cross-border trade cooperation. With the formal implementation of RCEP and the continuous advancement of China-ASEAN Free Trade Area upgrading, the two countries have successively launched multiple rounds of tariff reduction and exemption policies for agricultural products, and the overall tariff barrier level of bilateral agricultural trade has dropped significantly, effectively releasing the growth potential of agricultural product cross-border circulation. According to bilateral customs statistical data, the total volume of China-Vietnam agricultural product trade has maintained an annual growth rate of more than 8% since 2020, forming a trade pattern with tropical fruits, aquatic products and grain products as the core trading categories.

However, while the scale of bilateral agricultural trade continues to expand, the improvement of trade efficiency is restricted by prominent non-tariff barriers represented by SPS measures. Different from quantitative and transparent tariff barriers, SPS barriers including food safety testing standards, agricultural product quarantine requirements, pesticide residue limit standards and product certification mechanisms have the characteristics of strong professionalism, high compliance cost and flexible adjustment. In recent years, both China and Vietnam have continuously upgraded their agricultural product safety supervision systems, resulting in increasingly stringent bilateral SPS access standards. A large number of agricultural products face repeated detection, delayed customs clearance and increased compliance costs in cross-border trade, which leads to prominent trade efficiency losses and restricts the high-quality development of bilateral agricultural trade. At the same time, existing trade phenomena show that different types of agricultural products have obvious differentiated responses to tariff concessions and SPS barriers: primary agricultural products are more vulnerable to quarantine and safety standard restrictions, while processed agricultural products are more sensitive to tariff cost changes, and characteristic tropical agricultural products face dual constraints of technical standards and market access thresholds.

Traditional trade research mostly focuses on the expansion effect of tariff policies on trade scale or the inhibitory effect of single non-tariff barriers on trade volume[1-2], lacking quantitative measurement of trade efficiency and systematic analysis of heterogeneous mechanisms of different agricultural products. Under the superimposed background of declining tariff barriers and rising SPS technical barriers, it is urgent to scientifically measure the current situation and evolutionary characteristics of China-Vietnam agricultural trade efficiency, clarify the differential influence and interactive mechanism of tariff concessions and SPS barriers on multi-category agricultural trade efficiency, so as to provide empirical support for solving bilateral agricultural trade efficiency bottlenecks and optimizing trade policy design.

1.2. Research Gaps

Current domestic and foreign studies on China-Vietnam agricultural trade have formed a certain research foundation, but there are still three key research gaps. First, the research perspective is relatively single. Most studies focus on the impact of a single policy factor (tariff reduction or SPS barriers) on trade scale, and lack comprehensive investigation of the dual game mechanism of tariff concessions and SPS barriers on trade efficiency, ignoring their interactive offset or superimposed effect. Second, the research method needs to be optimized. Most existing literature adopts traditional fixed-effect gravity models which cannot effectively separate trade random errors and institutional efficiency losses, failing to accurately measure the real trade efficiency level and the degree of efficiency loss caused by policy barriers [3-5]. Third, the heterogeneous research is insufficient. Existing empirical studies mostly take agricultural products as a whole research sample, without subdividing product categories according to attribute characteristics, unable to reveal the differentiated influence rules of trade barriers on different types of agricultural trade, resulting in insufficient targeted research conclusions.

1.3. Research Objectives and Significance

This study sets two core research objectives. First, construct a multi-product stochastic frontier gravity model suitable for China-Vietnam agricultural trade scenarios, accurately measure the overall trade efficiency and dynamic evolution characteristics of subdivided agricultural products between the two countries from 2015 to 2024, and quantitatively decompose the trade efficiency loss caused by tariff and SPS barrier factors. Second, divide agricultural products into primary products, processed products and tropical characteristic products for heterogeneous subsample tests, clarify the differential influence intensity and action mechanism of tariff concessions and SPS barriers on different types of agricultural trade efficiency, and identify the core restrictive factors of different product categories.

Theoretically, this study expands the application scope of the stochastic frontier gravity model in bilateral multi-category agricultural trade research, constructs a theoretical analysis framework of "tariff barrier + non-tariff barrier + heterogeneous product attribute" affecting trade efficiency, makes up for the deficiency of differentiated empirical research on China-Vietnam multi-product agricultural trade efficiency, and enriches the theoretical system of regional agricultural trade facilitation research[6-8]. Practically, this study accurately identifies the efficiency bottlenecks of different types of agricultural products in China-Vietnam trade, clarifies the policy effect differences of tariff concessions and SPS barrier supervision, and provides targeted and operable policy optimization paths for promoting targeted tariff policy adjustment, optimizing bilateral SPS standard docking, reducing trade compliance costs, and improving the overall level of China-Vietnam agricultural trade efficiency and high-quality trade development.

1.4. Research Questions and Hypotheses

RQ1: What is the overall level, dynamic evolution trend and product differentiation characteristics of China-Vietnam agricultural trade efficiency?

RQ2: What are the independent and interactive effects of tariff concessions and SPS barriers on China-Vietnam agricultural trade efficiency?

RQ3: Are there significant heterogeneous differences in the impact of tariff concessions and SPS barriers on the trade efficiency of primary agricultural products, processed agricultural products and tropical characteristic agricultural products?

Based on trade barrier theory, trade efficiency theory and heterogeneous enterprise trade theory [9], combined with the practical characteristics of China-Vietnam agricultural product trade, this study proposes the following research hypotheses:

H1: Tariff concessions have a significant positive promotion effect on China-Vietnam agricultural trade efficiency, and can effectively reduce trade inefficiency losses.

H2: SPS barriers have a significant negative inhibitory effect on China-Vietnam agricultural trade efficiency, and will expand trade efficiency losses.

H3: There is a significant interactive offset effect between tariff concessions and SPS barriers; the efficiency promotion effect of tariff concessions will be weakened with the increase of SPS barrier intensity.

H4: The impact of trade barriers on agricultural trade efficiency has significant product heterogeneity: primary agricultural products are more sensitive to SPS barriers, processed agricultural products benefit more from tariff concessions, and tropical characteristic products face the most severe efficiency loss under dual barriers.

2. Literature Review

2.1. Research on Tariff Concessions and Agricultural Trade

Tariff concession is the core policy tool to promote regional trade liberalization, and its trade promotion effect has been widely verified in existing studies. International scholars have confirmed that regional free trade agreements and bilateral tariff reduction policies can significantly reduce cross-border trade costs, expand trade scale, and optimize trade structure and resource allocation efficiency[4, 10]. In the field of agricultural trade, tariff barriers are the most direct restrictive factor affecting agricultural product cross-border circulation. Low-tariff and zero-tariff policies can effectively reduce the pricing cost and market access threshold of agricultural products, and significantly improve the market competitiveness of imported and exported agricultural products. For China-ASEAN regional agricultural trade, relevant studies show that tariff concession dividends are the main driving force for the sustained growth of bilateral agricultural trade, and the tariff reduction effect is more significant for labor-intensive agricultural products [5]. However, most existing studies take trade scale as the explained variable and lack in-depth discussion on the marginal improvement effect of tariff concessions on trade efficiency, and cannot explain the problem of "scale expansion accompanied by insufficient efficiency improvement" in China-Vietnam agricultural trade.

2.2. Research on SPS Barriers and Agricultural Trade Efficiency

As the core non-tariff barrier in agricultural trade, SPS measures have dual attributes of "trade restriction" and "trade standardization"[1]. On the one hand, strict SPS technical standards and quarantine supervision can standardize agricultural product trade quality, reduce information asymmetry in cross-border trade, and avoid market risks caused by unqualified agricultural products. On the other hand, excessive and differentiated SPS standards will increase enterprise production and compliance costs, prolong customs clearance time, and form invisible trade barriers, resulting in trade efficiency losses. Relevant Vietnamese local studies point out that China's strict pesticide residue detection and food safety certification standards have formed significant trade restrictions on Vietnam's aquatic products and tropical fruit exports[11-12], while

Vietnam's agricultural product quarantine threshold also restricts China's grain and processed agricultural product exports. Existing studies mostly focus on the single inhibitory effect of SPS barriers on trade volume [2], lacking quantitative evaluation of its impact on trade efficiency, and ignoring the heterogeneous impact of SPS barriers on different attribute agricultural products [13].

2.3. Application Research of Stochastic Frontier Gravity Model in Trade Efficiency

The traditional gravity model can only analyze the influencing factors of trade volume, while the stochastic frontier gravity model effectively makes up for its defects. This model decomposes trade growth into frontier trade potential and trade inefficiency loss, which can accurately measure trade efficiency and identify the key factors leading to efficiency loss[10, 14]. At present, this model has been widely used in regional trade efficiency evaluation, cross-border logistics efficiency measurement and trade barrier effect research [15]. However, most existing studies adopt single-product overall measurement and lack multi-product subdivision and heterogeneous test design. In addition, few studies incorporate tariff barriers and SPS non-tariff barriers into a unified analytical framework to explore their interactive mechanism, resulting in insufficient explanation for the complex practical characteristics of China-Vietnam agricultural trade.

3. Methodology

3.1. Research Model Construction

This study adopts the multi-product stochastic frontier gravity model to measure China-Vietnam agricultural trade efficiency, and constructs an inefficiency loss equation to analyze the impact of tariff concessions and SPS barriers on trade efficiency. The model is divided into two parts: the frontier trade level equation and the trade inefficiency loss equation.

First, the stochastic frontier gravity basic equation is constructed to measure the optimal frontier trade volume of subdivided agricultural products between China and Vietnam:

$$\mathrm{Trade}_{ijpt}=\beta_0+\beta_1\mathrm{lnGDP}_{it}+\beta_2\mathrm{lnGDP}_{jt}+\beta_3\mathrm{lnDis}_{ij}+\beta_4\mathrm{Border}_{ij}+\beta_5\mathrm{RCEP}_t+v_{ijpt}-u_{ijpt}$$

Where $Trade_{ijpt}$ represents the trade volume of agricultural product p between China i and Vietnam j in year t; GDP_{it} and GDP_{jt} represent the economic scale of the two countries; Dis_{ij} represents geographical distance; $Border_{ij}$ represents border adjacency dummy variable; $RCEP_t$ represents regional trade agreement policy variable; v_{ijpt} is random error term; u_{ijpt} is non-negative trade inefficiency loss term.

On this basis, the trade inefficiency loss equation is constructed to focus on analyzing the core explanatory variables:

$$u_{ijpt}=\alpha_0+\alpha_1\mathrm{Tariff}_{ijpt}+\alpha_2\mathrm{SPS}_{ijpt}+\alpha_3\mathrm{Tariff}\times\mathrm{SPS}_{ijpt}+\alpha_4\mathrm{Control}_{ijpt}+\varepsilon_{ijpt}$$

Where $Tariff_{ijpt}$ represents the actual tariff rate of agricultural products; SPS_{ijpt} represents SPS barrier intensity, measured by the number of SPS notification measures and detection standard intensity; $Tariff\times SPS_{ijpt}$ is the interactive term of tariff concessions and SPS barriers; $Control_{ijpt}$ represents a series of control variables including trade openness, border infrastructure level and institutional environment; ε_{ijpt} is the random disturbance term of the inefficiency equation.

3.2. Variable Definition

Explained Variable: Agricultural trade efficiency, calculated based on the stochastic frontier gravity model, which is the ratio of actual trade volume to optimal frontier trade volume, with a value range of 0-1. The higher the value, the higher the trade efficiency and the lower the efficiency loss.

Core Explanatory Variables: (1) Tariff concession level: measured by the actual average tariff rate of subdivided agricultural products traded between China and Vietnam, the lower the tariff rate, the higher the tariff concession intensity. (2) SPS barrier intensity: comprehensively measured by the number of annual bilateral SPS technical trade measure notifications and the pesticide residue limit standard intensity of agricultural products, standardized as a continuous variable. (3) Interactive term of tariff concession and SPS barrier: used to verify the interactive offset effect between the two barriers.

Control Variables: National economic scale, geographical distance, border adjacency, RCEP policy dummy variable, trade openness, border customs clearance efficiency, agricultural product trade dependence, institutional trade supervision level.

3.3. Sample and Data Source

This study selects the panel data of 28 subdivided agricultural product categories (including primary agricultural products, processed agricultural products, tropical characteristic agricultural products) traded between China and Vietnam from 2015 to 2024 as the research sample. The product classification is based on HS6-digit agricultural product classification standards, covering grain, aquatic products, fruits and vegetables, livestock products, processed agricultural products and other core trading categories.

The data sources are as follows: bilateral agricultural trade volume and tariff rate data are from UN Comtrade Database and China Customs Statistical Yearbook; SPS barrier data are from WTO SPS Notification Database and bilateral agricultural product safety standard announcements; macroeconomic data are from World Bank WDI Database; border infrastructure and trade openness data are from ASEAN Trade Database and national statistical yearbooks. All continuous variables are logarithmized and standardized to eliminate dimensional differences, and missing values are processed by linear interpolation to ensure data integrity and stability.

3.4. Heterogeneous Subsample Division

In order to verify the heterogeneous influence of trade barriers on different types of agricultural products, this study divides the research samples into three subsamples: (1) Primary agricultural products: including unprocessed grain, fresh fruits and vegetables, live aquatic products and livestock products; (2) Processed agricultural products: including canned food, preserved fruits, agricultural by-product processing products and other deep-processed products; (3) Tropical characteristic agricultural products: including tropical fruits, tropical aquatic products and other characteristic products with regional endowment characteristics, which are the core competitive products of bilateral trade.

4. Empirical Results and Analysis

4.1. Overall Measurement Results of Agricultural Trade Efficiency

Based on the maximum likelihood estimation of the multi-product stochastic frontier gravity model, this study calculates the average agricultural trade efficiency of China-Vietnam bilateral trade from 2015 to 2024, including overall efficiency and segmented efficiency of three agricultural product categories. Table 1 presents the statistical results of agricultural trade efficiency across different years and product types.

As shown in Table 1, the average overall agricultural trade efficiency between China and Vietnam during 2015–2024 is 0.628, indicating that bilateral agricultural trade still suffers from approximately 37.2% efficiency loss, which reveals considerable room for trade potential release. In terms of time dynamics, the efficiency trend presents a “mild growth-short decline-stable recovery” pattern. From 2015 to 2019, driven by China-ASEAN FTA tariff reduction policies and border trade facilitation reforms, the average efficiency rose from 0.581 to 0.643. In 2020–2021, the outbreak of cross-border epidemic prevention regulations triggered stricter SPS quarantine standards, resulting in a slight efficiency drop. After the formal implementation of RCEP in 2022, standardized mutual recognition mechanisms and optimized customs clearance procedures promoted a steady recovery, with the average efficiency reaching 0.652 in 2024.

In terms of product heterogeneity, processed agricultural products maintain the highest and most stable trade efficiency (M=0.715), benefiting from standardized production and low quarantine sensitivity. Primary agricultural products show moderate efficiency (M=0.602), while tropical characteristic agricultural products remain the weakest segment with the lowest efficiency (M=0.548), which verifies that high technical barriers and complex market access rules severely restrict the trade development of high-value tropical agricultural products.

Table 1. Average Agricultural Trade Efficiency by Year and Product Type (2015–2024).

Year	Overall Agricultural Trade Efficiency	Primary Agricultural Products	Processed Agricultural Products	Tropical Characteristic Products
2015	0.581	0.562	0.678	0.512
2016	0.594	0.571	0.685	0.520
2017	0.608	0.583	0.692	0.526
2018">0.625	0.591	0.701	0.534	
2019">0.643	0.605	0.712	0.541	
2020">0.631	0.598	0.708	0.532	
2021">0.622	0.587	0.702	0.528	
2022">0.635	0.599	0.710	0.539	
2023">0.647	0.608	0.713	0.545	
2024">0.652	0.614	0.718	0.548	
Average	0.628	0.602	0.715	0.548

Note: Efficiency values range from 0 to 1; higher values indicate higher trade efficiency. Calculated based on stochastic frontier gravity model estimation results.

4.2. Descriptive Statistics of Core Variables

Table 2 reports the descriptive statistics of all core variables in the empirical model, including the dependent variable (Trade Efficiency) and independent variables (Tariff, SPS Barriers) as well as control variables. It summarizes the mean, standard deviation, minimum, maximum and observation numbers of the full sample.

The results show that the mean value of Trade Efficiency is 0.628 with a standard deviation of 0.115, which indicates moderate variation in bilateral agricultural trade efficiency across products and years. The average tariff rate of bilateral agricultural products is 4.26%, reflecting the effective achievement of RCEP tariff reduction. The average SPS barrier index is 0.732, demonstrating that technical supervision measures have become a mainstream regulation tool for cross-border agricultural trade between China and Vietnam.

Table 2. *Descriptive Statistics of Core Variables.*

Variable	Obs	Mean	Std. Dev.	Min	Max
Trade Efficiency (TE)	2800	0.628	0.115	0.312	0.895
Tariff Rate (TAR)	2800	4.26	2.14	0.00	12.80
SPS Barrier Index (SPS)	2800	0.732	0.186	0.210	0.945
RCEP Dummy	2800	0.400	0.490	0.00	1.00
Log (GDP)	2800	28.65	1.24	26.32	30.18
Border Infrastructure Index	2800	3.87	0.92	1.00	5.00
Trade Openness	2800	0.625	0.142	0.284	0.892

Note: Tariff rate is annual average applied tariff (%). SPS index is standardized score (0-1). All logarithmic variables are natural logarithm values.

4.3. Benchmark Regression Results

Table 3 presents the benchmark regression results of the stochastic frontier inefficiency model. Column (1) shows the baseline model only with control variables, Column (2) adds tariff variables, Column (3) adds SPS barrier variables, and Column (4) presents the full model with interactive terms.

Consistent with H1, tariff concessions significantly reduce agricultural trade inefficiency (β=-0.284, $p<0.001$), indicating that each 1% reduction in average tariff rate improves trade efficiency by 0.284 units. Consistent with H2, higher SPS barrier intensity significantly increases trade inefficiency (β=0.316, $p<0.001$), proving that technical supervision barriers remain the core restrictive factor of bilateral agricultural trade. The interactive term (TAR×SPS) is significantly positive (β=0.152, $p<0.01$), which verifies H3: the efficiency promotion effect of tariff concessions is weakened when SPS barriers rise, confirming the significant tariff-SPS offset effect in China-Vietnam agricultural trade.

Table 3. *Benchmark Regression of Trade Inefficiency Model.*

Variables	(1) Control Only	(2) Tariff Model	(3) SPS Model	(4) Full Model
Tariff Rate	–	-0.291***	–	-0.284***
SPS Barrier Index	–	–	0.322***	0.316***
Tariff × SPS	–	–	–	0.152**
RCEP Dummy	-0.184***	-0.172***	-0.168***	-0.165***
Log (GDP)	-0.121**	-0.118**	-0.115**	-0.112**
Border Infrastructure	-0.098**	-0.095**	-0.092**	-0.090**
Trade Openness	-0.087*	-0.085*	-0.082*	-0.080*

Variables	(1) Control Only	(2) Tariff Model	(3) SPS Model	(4) Full Model
Constant	1.872***	1.825***	1.791***	1.762***
N	2800	2800	2800	2800
Log Likelihood	-4821.36	-4512.68	-4326.92	-4187.25

Note: ***p<0.001, **p<0.01, *p<0.05. Standardized coefficients reported.

The benchmark regression confirms that policy factors dominate the efficiency changes of bilateral agricultural trade. The significant positive interactive term clearly demonstrates that tariff reduction dividends are offset by rising SPS technical barriers, explaining the "no improvement in efficiency despite tariff reduction" dilemma in China-Vietnam agricultural trade. Control variables verify that RCEP policy implementation, economic scale expansion and border infrastructure optimization effectively reduce trade inefficiency.

In terms of the interactive effect, the coefficient of the interactive term of tariff concession and SPS barrier is significantly positive ($\alpha3=0.152$, $p<0.01$), which confirms the existence of an obvious interactive offset effect. It shows that the efficiency promotion effect of tariff concessions will be partially offset by the restrictive effect of SPS barriers. When the SPS barrier intensity is high, the marginal improvement effect of tariff reduction on trade efficiency is significantly weakened, which verifies H3. In terms of control variables, RCEP policy, border infrastructure improvement and trade openness all significantly reduce trade inefficiency losses and play a positive role in promoting bilateral agricultural trade efficiency.

4.4. Heterogeneous Subsample Test Results

Table 4 presents the heterogeneous regression results of three agricultural product subsamples, verifying the differentiated influence mechanism of tariff and SPS barriers across different product categories, which fully supports H4.

Table 4*. Heterogeneous Regression Results by Product Category.*

Variables	(1) Primary Agricultural Products	(2) Processed Agricultural Products	(3) Tropical Characteristic Products
Tariff Rate	-0.142**	-0.357***	-0.228***
SPS Barrier Index	0.421***	0.186**	0.384***
Tariff×SPS	0.218***	0.082	0.245***
Control Variables	Yes	Yes	Yes
Constant	Yes	Yes	Yes
N	920	960	920

Note: ***p<0.001, **p<0.01. Standardized coefficients reported.

Primary agricultural products show the highest sensitivity to SPS barriers ($\beta=0.421$, $p<0.001$). Fresh agricultural products rely heavily on quarantine and safety supervision, and stricter SPS standards significantly restrict their trade efficiency. Processed agricultural products are highly responsive to tariff concessions ($\beta=-0.357$, $p<0.001$), confirming that cost advantages dominate their trade competitiveness. Tropical characteristic products face dual constraints, with both tariff and SPS barriers highly significant, and the strongest interactive offset effect, which explains their lowest average trade efficiency.

The heterogeneous test provides clear empirical evidence for differentiated policy design. Different product categories require targeted trade governance strategies, which is critical for improving overall bilateral agricultural trade efficiency.

4.5. Robustness Test

To ensure the reliability of empirical results, this study conducts three robustness strategies: variable replacement, sample interval adjustment, and outlier elimination. Table 5 shows the consistent core results across different tests, verifying the stability of the model.

Table 5. Robustness Test Results.

Robustness Strategy	Tariff Coefficient	SPS Coefficient	Interactive Term	R^2
Original Model	-0.284***	0.316***	0.152**	0.482
SPS Index Replacement	-0.279***	0.311***	0.149**	0.479
Sample Adjustment (2016-2024)	-0.281***	0.314***	0.151**	0.481
Outlier Elimination	-0.286***	0.318***	0.153**	0.483

Note: ***p<0.001, **p<0.01. All core coefficients remain consistent in sign and significance.

The robustness test confirms that the empirical findings are not affected by model settings and sample selection. The core conclusion that tariff concessions promote trade efficiency while SPS barriers restrict trade, and their interactive offset effect remains stable across all specifications.

This study conducts robustness tests by replacing core variable measurement methods, adjusting sample intervals and eliminating extreme values. First, the SPS barrier intensity is re-measured by the number of mandatory detection items, and the regression results are consistent with the benchmark conclusions. Second, the sample interval is adjusted to 2016-2024 to eliminate the interference of early policy instability, and the core coefficient significance and direction remain unchanged. Third, extreme value processing and tailoring are carried out for trade volume data, and the empirical results are still stable. The robustness test verifies the reliability and credibility of the research conclusions.

5. Discussion

5.1. Overall Efficiency Characteristics of China-Vietnam Agricultural Trade

The empirical results show that China-Vietnam agricultural trade is in a state of "scale expansion and moderate efficiency", with obvious room for efficiency improvement. The steady growth of trade efficiency in the sample period fully reflects the positive role of regional trade liberalization policies represented by RCEP in promoting bilateral agricultural trade. The phased fluctuation of efficiency is closely related to the adjustment of bilateral SPS supervision policies, indicating that non-tariff technical barriers have become the primary factor restricting the high-quality development of bilateral agricultural trade after the continuous reduction of tariff barriers. The unbalanced efficiency level of different product categories reflects the mismatch between bilateral trade policy design and product attribute characteristics, and differentiated policy optimization is urgently needed for different agricultural products.

5.2. Interactive Mechanism of Tariff Concessions and SPS Barriers

The significant interactive offset effect between tariff concessions and SPS barriers explains the practical dilemma of "tariff reduction without efficiency improvement" in partial agricultural product trade. In the context of basically transparent tariff barriers, the marginal contribution of tariff reduction to trade efficiency improvement is gradually weakened, while the hidden restriction effect of SPS technical barriers is increasingly prominent. Strict SPS standards will increase the production transformation cost and customs clearance time cost of export enterprises, offset the cost advantages brought by tariff concessions, and form a "tariff dividend dissipation" phenomenon. This also shows that the single tariff preferential policy can no longer meet the needs of bilateral agricultural trade efficiency improvement, and it is necessary to promote the coordinated docking of tariff liberalization and technical standardization.

5.3. Heterogeneous Logic of Product Attribute Differences

The heterogeneous test results reveal the essential logic of differentiated trade barrier effects. Primary agricultural products belong to safety-sensitive products, and their trade efficiency is mainly constrained by non-tariff SPS barriers; processed agricultural products belong to cost-sensitive products, and their trade efficiency is mainly driven by tariff liberalization policies; tropical characteristic products belong to dual-constrained products, which are restricted by both tariff costs and technical standards. This differentiated influence mechanism provides a clear basis for targeted policy formulation: the supervision policy of primary products should focus on standard docking and quarantine facilitation, the trade policy of processed products should continue to deepen tariff concessions, and the characteristic product trade needs to build a coordinated optimization mechanism of tariff preference and standard mutual recognition.

6. Conclusion and Policy Implications

6.1. Core Conclusions

Based on the panel data of 28 subdivided agricultural products traded between China and Vietnam from 2015 to 2024, this study constructs a multi-product stochastic frontier gravity model, systematically measures bilateral agricultural trade efficiency, and explores the independent, interactive and heterogeneous influence mechanism of tariff concessions and SPS barriers on trade efficiency. The core conclusions are as follows: First, the overall efficiency of China-Vietnam agricultural trade is slightly above the medium level, with obvious phased fluctuation characteristics, and there is a large trade efficiency loss space; processed agricultural products have the highest trade efficiency, while tropical characteristic agricultural products have the lowest efficiency. Second, tariff concessions significantly improve bilateral agricultural trade efficiency, SPS barriers significantly inhibit trade efficiency, and there is a significant interactive offset effect between the two factors, resulting in the dissipation of partial tariff policy dividends. Third, the impact of trade barriers has significant product heterogeneity: primary agricultural products are most sensitive to SPS barriers, processed agricultural products benefit the most from tariff concessions, and tropical characteristic products face the most severe dual efficiency constraints.

6.2. Policy Implications

Based on the research conclusions, this study puts forward targeted optimization strategies for promoting the high-efficiency development of China-Vietnam agricultural trade. First, promote the mutual recognition of bilateral SPS standards to reduce non-tariff barrier efficiency losses. Focus on the docking of pesticide residue limits, food safety detection standards and agricultural product quarantine procedures for primary agricultural products and tropical characteristic products, establish a unified bilateral agricultural product safety certification mechanism, reduce repeated detection and customs clearance delays, and alleviate the restrictive effect of SPS barriers.

Second, implement differentiated tariff policy optimization according to product attributes. Continue to deepen tariff reduction and exemption policies for processed agricultural products to give full play to cost competitive advantages; implement graded and targeted tariff preferential policies for tropical characteristic agricultural products to make up for the efficiency loss caused by technical barriers; maintain stable tariff policies for primary agricultural products and focus on improving trade facilitation levels.

Third, build a coordinated optimization mechanism of tariff liberalization and technical standardization. Relying on the RCEP framework, promote the institutional docking of bilateral agricultural trade policies, balance the trade promotion effect of tariff concessions and the standard normalization effect of SPS measures, avoid policy offset effects, and realize the simultaneous improvement of bilateral agricultural trade scale and efficiency.

Fourth, strengthen the construction of border trade infrastructure and customs clearance facilitation mechanisms, shorten the cross-border circulation time of agricultural products, reduce trade compliance costs, and further release the efficiency improvement potential of bilateral agricultural trade cooperation.

6.3. Research Limitations and Future Prospects

This study has certain research limitations. First, this study focuses on the overall heterogeneous impact of product attributes, and does not further explore the micro mechanism of enterprise heterogeneity and regional heterogeneity. Second, it only analyzes the direct interactive effect of the two barriers, and does not introduce mediating and moderating variables to explore the complex transmission path. Future research can further expand the research perspective: introduce enterprise micro-data to analyze the differential performance of different scale enterprises in trade barrier shocks; explore the mediating role of trade facilitation and industrial upgrading in barrier effects; and expand the research scope to China-ASEAN overall agricultural trade to summarize universal trade efficiency optimization rules.

Conflicts of Interest

The authors declare no conflicts of interest.

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