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Driving Factors, Potential Measurement and Spatial Heterogeneity of China's Provincial-Level Trade Cooperation with South Korea

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Abstract: *Against the backdrop of the deepening China-South Korea Free Trade Area and the implementation of Regional Comprehensive Economic Partnership, this study examines provincial trade cooperation between China and South Korea using panel data from 2014-2023 and a time-varying stochastic frontier gravity model. The findings show that economic scale and innovation capacity significantly influence trade cooperation, while trade efficiency exhibits a four-layer gradient with uneven provincial potential. To enhance high-quality trade development, the study recommends adopting efficiency-based regional policies, strengthening key growth drivers, addressing non-efficiency constraints, and establishing long-term collaborative mechanisms to deepen China-South Korea economic cooperation.*

Keywords: *trade cooperation, influencing factors, trade potential, spatial heterogeneity*

1. Introduction

As two major East Asian economies, China and South Korea have developed a trade partnership that plays a vital role in economic growth and the optimization of global industrial chains. Bilateral trade exceeded USD 360B in both 2021 and 2022 and remained above USD 310B in 2023 despite sluggish global economic recovery and weakened external demand (General Administration of Customs People's Republic of China, 2021-2023). This performance underscores the resilience and vitality of bilateral trade. In recent years, driven by the continued implementation of the China-South Korea Free Trade Area (FTA), the entry into force of Regional Comprehensive Economic Partnership (RCEP), and shifts in the global trade landscape, trade between the two countries has continued to expand. Nevertheless, substantial differences in trade efficiency persist across Chinese provinces. In many regions, trade potential remains underutilized because of constraints such as limited innovation capacity, geographic distance, and uneven levels of trade facilitation.

Early studies examined issues such as shifts in the global economic landscape, the China-South Korea FTA, and the RCEP framework, often employing gravity models to assess the growth potential of and forces driving bilateral economic and trade cooperation. Many studies have used variables such as per capita gross domestic product, population size, tariffs, and trade facilitation as key determinants of Sino-Korean trade potential and efficiency[1][2]. Geographical distance influences not only transportation costs but also cultural and linguistic proximity. Shorter distances facilitate a finer international division of labor, increase cross-border trade in intermediate goods, and intensify trade linkages, thereby making trade volume more sensitive to changes in distance [3][4]. Currency appreciation against an international reference currency, such as the USD, generally promotes imports; however, its effect on exports is often offset by factors such as order cycles and product competitiveness. Large and frequent exchange-rate fluctuations increase uncertainty for importing firms, prompting them to reduce imports because of risk aversion[5][6]. Trade openness promotes international trade cooperation [7], while transportation infrastructure facilitates trade by lowering transaction and logistics costs[8]. Trade facilitation further promotes global trade by integrating new technologies, simplifying cross-border procedures, and reducing transaction costs[9]. Comprehensive innovation capability-encompassing product, process, and organizational innovation-is a fundamental driver of sustained economic growth. It promotes industrial upgrading, accelerates the commercialization of innovation outcomes, and enhances international trade competitiveness. Strong innovation capability increases returns to research and development, expands exports, and exerts a significant positive effect on bilateral trade[10].

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Most existing studies have examined Sino-Korean trade at the national level, with limited attention to the dynamic evolution of provincial trade efficiency and the sources of inefficiency within China. In addition, few studies have employed time-varying stochastic frontier models (SFAs) to capture temporal heterogeneity in trade efficiency. Because trade efficiency and potential evolve over time, static models may produce biased estimates by failing to account for changes in inefficiency. To address these gaps, this study uses panel data covering trade between South Korea and China's 31 provinces from 2014 to 2023 and applies a time-varying stochastic frontier gravity model to systematically examine provincial differences in trade efficiency and the determinants of inefficiency. It further proposes differentiated improvement strategies to support the high-quality, coordinated development of provincial trade with South Korea and deepen the strategic cooperative partnership between the two countries.

2. Models, Variables, and Data

2.1. Model Specification

The gravity model was first introduced into empirical trade research by Tinbergen. It is a quantitative framework used to predict trade volume, factor flows, and the intensity of economic interactions between countries or regions based on economic size and spatial distance. As one of the core empirical tools in international economics, it is expressed in Eq. 1. Here, T_{ijt} represents the trade volume between countries i and j; Y_i and Y_j denote the economic size of the two countries, measured in this study by per capita gross national product; DIS_{ij} represents the distance between countries i and j; and A is a proportionality constant.

$$T_{ij} = A\left(Y_{\mathrm{i}} \times {Y_{\mathrm{j}}}/{DIS_{ij}}\right) \tag{1}$$

This study aims to estimate frontier trade levels and identify the effects of factors such as economic scale and population size. Building on the traditional gravity model, additional explanatory variables are incorporated to construct a stochastic frontier gravity model, as shown in Eq. 2. Variable definitions are provided in Table 1. South Korea's innovation capability is treated as a fixed effect and incorporated into the constant term β_0 to control for its underlying influence. The term v_{ijt} represents the random error component that captures stochastic factors, whereas u_{ijt} denotes the trade inefficiency term, which distinguishes the SFA from the traditional gravity model.

$$\begin{aligned} InTRAD_{ijt} = {} & \beta_0 + \beta_1 \ln PGDP_{it} + \beta_2 \ln PGDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} + \\ & \beta_5 \ln DIS_{ij} + \beta_6 ER_{ij} + \beta_7 CIC_{it} + \beta_8 CIC_{jt} + v_{ijt} - u_{ijt} \end{aligned} \tag{2}$$

2.2. Trade Inefficiency Model

Existing studies have suggested that bilateral trade is influenced not only by economic factors but also by non-economic factors[11]. The trade inefficiency model allows the inclusion of exogenous variables to examine these effects. Accordingly, this study incorporates trade facilitation, transportation facilitation, and market facilitation (FTA, Con, and Mar), as shown in Eq. 3. Here, Z_{xyt} represents the exogenous variables, and α is the estimated parameter function associated with the disturbance term. The data sources for all variables are reported in Table 1.

$$\mu_{xyt} = \alpha Z_{xyt} + \varepsilon_{xyt} \tag{3}$$

Table 1. Variable selection and data sources.

Variable	Meaning	Source
Tradijt	Trade volume between China and South Korea	2014-2023 Provincial Statistical Yearbooks
Pgdpit	Economic scale of each province in China	
Pgdpjt	Size of Korean economy	World Bank Database
Popit	Population of each province in China	Provincial Statistical Yearbooks
Popjt	Population of South Korea	World Bank Database
Disij	Geographical distance (latitude/longitude provincial capitals and Seoul, South Korea)	Baidu Map
Er	Exchange rate	Bank of China
Cicit	Comprehensive innovation capability (+ secondary indicators such as full-time equivalent of research and	2014-2023 China Torch Statistical Yearbook

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Variable	Meaning	Source
	development (R&D) personnel, R&D expenditure, number of scientific and technological patents registered, and # patent applications)	
FTA	Trade facilitation (if there is a free trade zone)	Official Ministry of Commerce web site
Con	Transportation facilitation (port container throughput)	2014-2023 China Transportation Statistical Yearbook
Mar	Level of market facilitation (+ secondary indicators such as turnover rate of stock transactions and proportion of stock transactions per gross domestic product)	Wend Database

2.3. Statistical Testing

2.3.1. Descriptive Statistics

Comprehensive innovation capability is a key indicator of provincial innovation performance. To minimize subjective weighting bias, this study first applies the entropy method to synthesize four underlying indicators into a composite measure. Descriptive statistics for the 310 observations were generated using STATA 17. As shown in Table 2, trade between China and South Korea has expanded steadily over the past decade, although substantial differences remain among China's 31 provinces. Considerable variation is observed in trade scale, China's provincial population size, and comprehensive innovation capability. Transportation facilitation exhibits the greatest dispersion, with a standard deviation of 1,358.00. This reflects the use of port container throughput as the measurement indicator and the absence of ports in many inland provinces.

Table 2. Descriptive analysis

Item	Sample Size	Average	Maximum	Minimum	Median	Standard Deviation
lnTrade	310	3.00	6.75	–3.51	3.43	2.17
lnpGdpit	310	11.01	12.21	10.13	10.95	0.43
lnpGdpjt	310	10.36	10.47	10.27	10.37	0.06
lnPopit	310	8.14	9.45	5.78	8.28	0.84
lnPopjt	310	8.55	8.55	8.53	8.55	0.01
Disij	310	7.28	8.12	6.34	7.23	0.46
Er	310	6.64	7.05	6.14	6.68	0.28
Cicit	310	0.12	0.99	0.00	0.07	0.16
FTA	310	0.40	1.00	0.00	0.00	0.49
Con	310	711.70	6490.00	0.00	50.00	1,358.00
Mar	310	0.03	0.16	0.01	0.02	0.02

2.3.2. Applicability Test

To evaluate the suitability of the SFA framework for trade-efficiency estimation, this study tests two core hypotheses: the absence of a trade inefficiency term and the absence of time variation in the inefficiency term. The results reported in Table 3 indicate that, for China's trade volume with South Korea, the null hypothesis of no inefficiency term is rejected at the 1% level ($p = 0.0042$), confirming the presence of significant inefficiency effects. Because the ordinary least squares (OLS) model does not account for inefficiency, it is subject to estimation bias. The SFA framework is therefore more appropriate. The test of the null hypothesis that the inefficiency term does not vary over time yields a p-value of 0.095, indicating that trade inefficiency exhibits temporal variation. That is, inefficiency factors change over time across provinces. These results support the use of a time-varying SFA to capture the dynamic nature of trade efficiency.

Table 3. Model applicability test results

Dependent Variable	Null Hypothesis	Constraint	Non-Coercive	Likelihood Ratio	p	Inspection Result
lnTrade	No trade inefficiency factor	–186.6296	–182.52756	8.20	0.0042	Reject H0
	Non-efficiency items do not change	–182.52756	–181.13733	2.78	0.0954	Reject H0

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2.4. Result Analysis

2.4.1. Random Frontier Gravity Model

To identify the determinants of China-South Korea trade, this study uses total bilateral trade volume as the dependent variable and compares the results of an OLS model, a time-invariant SFA, and a time-varying SFA. The OLS model serves as the benchmark specification, whereas the SFA models separate frontier trade performance from trade inefficiency, allowing a more accurate assessment of the effects of explanatory variables. Full details are provided in Table 4.

Table 4. Random frontier gravity-model results.

Variable	Ordinary Least Squares (OLS) Results			Time-Invariant Stochastic Frontier Analysis (SFA) Results			Time-Varying SFA Results		
	Coefficient	Standard Error	t	Coefficient	Standard Error	t	Coefficient	Standard Error	t
lnpGdpit	2.829***	(0.138)	(20.46)	1.589***	(0.205)	(7.74)	2.355***	(0.392)	(6.01)
lnpGdpjt	–2.867*	(1.534)	(–1.87)	–0.986	(0.717)	(–1.38)	–1.035	(0.717)	(–1.44)
lnPopit	1.476***	(0.0597)	(24.73)	1.440***	(0.136)	(10.60)	1.178***	(0.262)	(4.49)
lnPopjt	–33.52*	(19.55)	(–1.72)	–18.85**	(8.625)	(–2.19)	–17.49**	(8.718)	(–2.01)
lnDis	–0.969***	(0.120)	(–8.07)	–1.401***	(0.285)	(–4.92)	–1.256***	(0.357)	(–3.52)
Er	–0.457	(0.313)	(–1.46)	–0.279**	(0.136)	(–2.05)	–0.231*	(0.138)	(–1.67)
constant term	286.1*	(152.9)	(1.87)	158.9**	(68.13)	(2.33)	142.3**	(69.04)	(2.06)
σ^2				–0.000948	(0.304)	(–0.00)	–0.153	(0.297)	(–0.52)
γ				1.929***	(0.362)	(5.33)	1.748***	(0.371)	(4.72)
μ				1.699***	(0.294)	(5.77)	4.232	(3.175)	(1.33)
θ							–0.0163	(0.014)	(–1.16)
R2	0.854			-			-		
log likelihood	–381.3099			–182.52756			–181.13733		
Likelihood ratio	-			8.20			2.78		

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

China's population size is positive and significant at the 1% level across all three models, indicating that a larger population promotes bilateral trade through expanded labor resources and consumer markets. In contrast, South Korea's population size exhibits a negative coefficient in both the OLS and SFAs. In the time-varying model, the coefficient reaches −17.49. As a developed economy with a relatively mature domestic market, South Korea's population size appears to exert a diminishing marginal effect on trade growth, which depends more heavily on technological advantages than on population expansion.

Geographical distance is negative and significant at the 1% level in all three models, consistent with the traditional gravity-model prediction that greater distance increases transportation and information costs, thereby reducing trade volume.

The exchange rate is significantly negative only in the time-invariant and time-varying SFAs. This suggests that OLS, by ignoring inefficiency effects, fails to capture the adverse impact of exchange-rate movements on trade. After separating inefficiency effects, the SFA models indicate that RMB appreciation reduces export price competitiveness and lowers overall trade volume. This finding further demonstrates the advantage of the time-varying SFA model in identifying the underlying effects of explanatory variables. The constant term is significantly positive across all models, suggesting that omitted factors generally support bilateral trade. The continued implementation of the China-South Korea FTA and the entry into force of RCEP have likely contributed to trade expansion by reducing trade barriers.

2.4.2. Trade Inefficiency Model

Building on the preceding analysis, this study further employs a trade inefficiency model to examine the determinants of China-South Korea trade cooperation. The results are reported in Table 5.

Table 5. Trade inefficiency model results.

Random Frontier Gravity Model				Trade Inefficiency			
Variable	Coefficient	Standard Error	t	Variable	Coefficient	Standard Error	t
lnPgdpit	2.100***	0.103	20.33	Cic	–0.0129***	0.00337	–3.84

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Random Frontier Gravity Model				Trade Inefficiency			
Variable	Coefficient	Standard Error	t	Variable	Coefficient	Standard Error	t
lnPgdpjt	–1.240*	0.696	–1.78	FTA	–0.00181***	0.000478	–3.80
lnPopit	1.262***	0.0491	25.70	Con	–0.00000173**	0.000000817	–2.12
lnPopjt	–19.99**	9.005	–2.22	Mar	–0.00108	0.00957	–0.11
lnDis	–1.529***	0.125	–12.19	constant term	160.2***	67.13	2.12
Er	–0.281**	0.140	–2.00				
constant term	165.5**	71.17	2.33				
				σ^2	–7.347***	0.255	–28.79
				γ	4.803***	0.272	17.68
				log likelihood	1334.4252		
				likelihood ratio	2705.41		

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Overall, the trade inefficiency model demonstrates a satisfactory fit. The log-likelihood value is 1,334.4252, while the likelihood ratio statistic reaches 2,705.41 and is statistically significant, confirming the validity of the model specification. The results indicate that comprehensive innovation capability, FTAs, and transportation facilitation significantly influence trade inefficiency between China and South Korea, whereas market facilitation does not have a statistically significant effect.

The coefficient of comprehensive innovation capability is −0.0129 and is significant at the 1% level, indicating that stronger innovation capability enhances product competitiveness, reduces transaction costs and uncertainty, and improves trade efficiency. As a result, trade inefficiency declines. The coefficient of FTA is −0.00181 and is also significant at the 1% level, confirming the role of FTAs in reducing inefficiency. By lowering tariff barriers, simplifying customs procedures, and harmonizing rules and standards, the China-South Korea FTA reduces trade frictions and promotes more efficient bilateral trade.

Transportation facilitation has a coefficient of −0.00000173. Although statistically significant, its small magnitude suggests that further improvements in transportation infrastructure currently generate only limited gains in trade efficiency. This may reflect the already well-developed logistics networks linking China and South Korea, leaving relatively little room for improvement through traditional infrastructure expansion. Future gains are therefore more likely to come from smart-port development and deeper cross-border logistics integration.

The coefficient of market facilitation is positive but statistically insignificant, indicating that the level of capital-market facilitation, as measured by stock-trading indicators, has no discernible effect on provincial trade inefficiency with South Korea. This result may reflect the relatively weak integration of Chinese and South Korean capital markets during the sample period or the limited relevance of the selected indicators to trade facilitation. Future research should consider alternative measures more closely related to trade activities, such as cross-border payment efficiency and trade-financing accessibility.

2.5. Analysis of Trade Efficiency and Potential

This study examines the evolution of trade efficiency and trade potential between China's provinces and South Korea from 2014 to 2023. Based on average values and annual data, provinces are classified into different efficiency gradients. The results indicate a general pattern of declining trade efficiency alongside rising trade potential, with substantial regional variation. The results are reported in Table 6.

Table 6. Trade efficiency between Chinese provinces and South Korea (2014–2023).

Province	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean	Gradient
Guangdong	0.116	0.112	0.108	0.104	0.101	0.097	0.093	0.090	0.086	0.083	0.099	1
Chongqing	0.095	0.091	0.088	0.085	0.081	0.078	0.075	0.072	0.069	0.066	0.080	1
Shanxi	0.088	0.084	0.081	0.078	0.075	0.072	0.069	0.066	0.063	0.060	0.073	1
Tianjin	0.069	0.066	0.063	0.060	0.058	0.055	0.053	0.050	0.048	0.045	0.057	2
Hainan	0.067	0.064	0.061	0.059	0.056	0.053	0.051	0.048	0.046	0.044	0.055	2
Sichuan	0.051	0.049	0.046	0.044	0.042	0.040	0.038	0.036	0.034	0.032	0.041	2
Shandong	0.043	0.041	0.039	0.037	0.035	0.033	0.031	0.030	0.028	0.026	0.034	2
Jiangxi	0.042	0.040	0.038	0.036	0.034	0.032	0.030	0.029	0.027	0.025	0.033	2

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Province	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean	Gradient
Jiangsu	0.040	0.038	0.036	0.034	0.032	0.030	0.028	0.027	0.025	0.024	0.031	2
Henan	0.036	0.034	0.032	0.031	0.029	0.027	0.026	0.024	0.023	0.021	0.028	3
Guangxi	0.033	0.032	0.030	0.028	0.027	0.025	0.024	0.022	0.021	0.020	0.026	3
Shanghai	0.032	0.031	0.029	0.027	0.026	0.024	0.023	0.021	0.020	0.019	0.025	3
Liaoning	0.031	0.030	0.028	0.026	0.025	0.023	0.022	0.021	0.019	0.018	0.024	3
Ningxia	0.031	0.030	0.028	0.026	0.025	0.023	0.022	0.021	0.019	0.018	0.024	3
Gansu	0.029	0.027	0.026	0.024	0.023	0.021	0.020	0.019	0.018	0.017	0.022	3
Fujian	0.026	0.024	0.023	0.022	0.020	0.019	0.018	0.017	0.016	0.015	0.020	3
Zhejiang	0.024	0.023	0.021	0.020	0.019	0.018	0.017	0.016	0.014	0.014	0.019	3
Henan	0.024	0.022	0.021	0.020	0.018	0.017	0.016	0.015	0.014	0.013	0.018	3
Hunan	0.021	0.020	0.018	0.017	0.016	0.015	0.014	0.013	0.012	0.011	0.016	3
Shanxi	0.021	0.020	0.019	0.017	0.016	0.015	0.014	0.013	0.012	0.012	0.016	3
Anhui	0.018	0.017	0.016	0.015	0.014	0.013	0.012	0.011	0.011	0.010	0.014	3
Guizhou	0.018	0.016	0.015	0.014	0.013	0.013	0.012	0.011	0.010	0.009	0.013	3
Hubei	0.015	0.014	0.013	0.012	0.011	0.010	0.010	0.009	0.008	0.008	0.011	3
Jilin	0.013	0.012	0.011	0.011	0.010	0.009	0.008	0.008	0.007	0.007	0.010	3
Beijing	0.012	0.012	0.011	0.010	0.009	0.009	0.008	0.007	0.007	0.006	0.009	4
Qingdao	0.012	0.011	0.011	0.010	0.009	0.008	0.008	0.007	0.007	0.006	0.009	4
Yunnan	0.012	0.011	0.010	0.009	0.009	0.008	0.007	0.007	0.006	0.006	0.008	4
Xizang	0.009	0.009	0.008	0.007	0.007	0.006	0.006	0.005	0.005	0.004	0.007	4
Xinjiang	0.010	0.009	0.008	0.008	0.007	0.007	0.006	0.006	0.005	0.005	0.007	4
Neimenggu	0.008	0.007	0.007	0.006	0.006	0.005	0.005	0.004	0.004	0.004	0.005	4
Heilongjiang	0.008	0.007	0.007	0.006	0.006	0.005	0.005	0.004	0.004	0.004	0.005	4
Mean value	0.034	0.032	0.031	0.029	0.028	0.026	0.025	0.023	0.022	0.021	0.027	-

From 2014 to 2023, the average trade efficiency of China's provinces with South Korea declined from 0.034 to 0.021, representing a decrease of 38.2% over the study period. All provinces exhibited a downward trend in trade efficiency. Guangdong, Chongqing, and Shaanxi consistently ranked among the top three provinces, whereas Heilongjiang and Inner Mongolia remained at the bottom. Table 7 presents the efficiency classification based on average provincial trade efficiency with South Korea during 2014–2023. Using the natural breaks method, the 31 provinces were divided into four gradients: the first gradient includes provinces with average efficiency ≥0.06; the second, 0.03≤ average efficiency <0.06; the third, 0.01≤ average efficiency <0.03; and the fourth, average efficiency <0.01.

Table 7. Trade potential between Chinese provinces and South Korea.

Province	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean value
Jiangsu	15262.2	15395.0	15061.9	18875.7	24607.4	22936.6	24702.6	31013.3	34155.0	30056.6	23206.63
Shanghai	7770.7	9245.3	8165.4	9248.6	10279.9	10406.4	11352.8	16045.2	16394.6	15079.5	11398.84
Zhejiang	5518.8	5283.4	6126.7	7650.9	9627.7	10272.4	12013.4	15369.8	17186.3	15054.7	10410.41
Shandong	8173.8	7864.7	7393.3	7777.0	8380.9	8535.8	9702.3	13333.2	14677.0	14338.0	10017.60
Beijing	8617.3	9428.6	8888.6	9733.5	10014.9	8291.2	6551.3	8718.9	8686.5	11378.8	9030.96
Guangdong	6292.9	5799.1	5714.3	6415.2	7410.7	6436.8	6024.4	7837.9	7124.5	6068.3	6512.41
Fujian	2410.5	2833.4	2818.6	2877.4	3426.9	3146.2	3436.6	5495.2	5753.9	5789.4	3798.81
Liaoning	3492.5	2907	2864.5	3859.2	3879.3	3707	2664.9	4199.8	4619.9	5013.4	3720.75
Hubei	1185	1498.2	1552.2	2278.3	2420.9	3413.9	4260.4	5065	6580.5	4961.6	3321.6
Henan	2122.7	2767.4	2006.8	2097.3	1696.6	1989.7	2720.1	4654.1	5430.1	4893.9	3037.87
Anhui	1273	1186.7	1044.4	1837.4	2196.5	2591	3464.4	4289.8	4937.4	5507	2832.76
Tianjin	2696.8	2322	1976.7	2045.2	2055.5	1843.1	1838.2	2404.7	2349.2	2128.7	2166.01
Hunan	495.8	745.3	722.6	968.6	1570.2	2286.9	2487.1	3298.5	3586	3815.3	1997.63
Hebei	1958.6	1469	1572.4	1509.8	2029.1	1843.7	1628.7	2430.6	2398	2471.8	1931.17
Sichuan	603.5	444.5	545.3	942.1	1335.8	1164.1	1587.8	2062.9	2857.9	2539	1408.29
Shanxi	325.6	466.9	648.5	947.9	1364.2	1472.1	1893.3	2373.3	2166.6	1615.6	1327.4
Jiangxi	364.6	622	746	833.8	857.9	1114.1	1419.2	1498.4	2152.3	1921.6	1152.99
Neimenggu	873.1	523.2	802.2	842.2	924.9	918.1	799.6	1778.5	1456.4	1764.7	1068.29
Chongqing	735.5	506	496.9	633.3	911.8	941.9	917.2	1102.4	1682.8	1476.1	940.39
Jilin	644	569	647.3	731.8	767.2	1146.9	921.9	1087.7	1276.4	1214.7	900.69
Shanxi	541.2	587.8	711.6	890.9	790.5	570.1	703.4	919.5	1212	895.9	782.29
Heilongjiang	629.6	505.8	270.5	322.6	396.5	545.2	691.5	906.9	1274.9	1507.3	705.08
Guangxi	211.3	113.8	129.9	217.3	269.6	274.3	433.8	550.4	979.1	1009.3	418.88
Yunnan	247.9	361.8	203.1	155.5	209.1	186	492.6	798.3	777.8	688.3	412.04
Guizhou	185.6	402.3	158.8	282.4	243.5	143	134	296.3	475.3	481.8	280.3
Xinjiang	267.2	127.6	95.6	112.5	93.2	133.4	202.8	246.2	209	323.5	181.1
Gansu	79.7	250.2	188.4	65.4	82.5	75.8	102.2	163	205.2	98.4	131.08

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Province	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean value
Hainan	40.5	64.4	67.6	81.3	84.3	62.8	86.1	127.7	127.3	196.1	93.81
Ningxia	67.7	120.8	51.3	169.6	64.2	61.3	46.4	103.3	135.4	102.2	92.22
Qinghai	18.2	114.5	177	25.9	55	35.5	17.9	19.7	38.4	60.9	56.3
Xizang	3.4	9.8	7.3	11.1	6.1	18.8	13.2	13	15.3	67.4	16.54
annual average	2358.36	2404.37	2317.93	2723.86	3162.99	3114.97	333.58	4458.18	4868.42	4597.41	6459.44

The efficiency gradient generally declines from coastal and highly open regions to central industrial provinces and then to more remote border regions. Guangdong, Shanghai, and Tianjin benefit from deep-water ports and dense maritime shipping networks connecting China and South Korea, resulting in lower logistics costs and higher efficiency. In contrast, border provinces such as Heilongjiang and Inner Mongolia face weaker logistics infrastructure, longer transportation cycles, and higher transportation costs, contributing to persistently low efficiency levels. Under the Belt and Road Initiative, Chongqing and Shanghai have benefited from trade-facilitation policies that have strengthened their efficiency advantages. By comparison, some western provinces have received less policy support, resulting in lower trade-facilitation levels and larger efficiency declines.

Despite declining trade efficiency, trade potential increased during the study period, driven by policy initiatives such as RCEP and by provincial efforts to expand product categories and develop new markets in South Korea. From a temporal perspective, provincial trade potential followed a three-stage pattern characterized by steady growth, short-term correction, and rapid rebound. Between 2014 and 2019, national average trade potential increased from 2358.36 to 3114.97, corresponding to an average annual growth rate of 10.8%. In 2020, the COVID-19 pandemic caused a correction in trade potential in more than 70% of provinces. Supply-chain disruptions led to declines of 18.2% and 15.7% in Hubei and Hunan, respectively. From 2021 to 2023, trade potential rebounded rapidly. Supported by the implementation of RCEP and enhanced trade-facilitation measures, the national average potential increased to 4597.41. Benefiting from industrial expansion in central China and the growth of China-Europe Railway Express services, Hubei and Hunan recorded increases of 114.6% and 53.4%, respectively, between 2020 and 2023, representing the fastest growth rates nationwide.

Regional differences in trade potential reveal a pattern of "head concentration, middle-tier growth, and border-region lag," accompanied by increasing polarization. In 2023, Jiangsu, Zhejiang, and Shandong ranked as the top three provinces in trade potential, jointly accounting for 42.3% of the national total. Among central provinces, Anhui and Hubei significantly expanded their trade potential through industrial transfers from the Yangtze River Delta and have moved into the upper-middle tier. In contrast, border provinces such as Heilongjiang and Inner Mongolia have remained at the lower end because their trade with South Korea is concentrated in resource-based products with relatively low value added. Liaoning and Shandong, two Bohai Rim coastal provinces, maintained comparatively stable growth through the development of local economic cooperation demonstration zones under the China-South Korea FTA. Their trade potential fluctuated by less than 15% during 2014-2023, making them important stabilizing forces in regional trade development. The results are reported in Table 7.

3. Countermeasures and Suggestions

3.1. Implement Policies Based on Efficiency Gradients to Address Regional Trade Imbalances

Given the four-tier gradient structure of provincial trade efficiency with South Korea during 2014-2023, differentiated regional development strategies should be adopted. For first-gradient provinces such as Guangdong, efforts should focus on strengthening collaboration and innovation in high-end industries. Leveraging the advantages of the Pearl River Delta industrial cluster, the New International Land-Sea Trade Corridor, and China-South Korea industrial parks, these provinces should prioritize sectors such as electronic information and new energy, deepen technological cooperation with leading South Korean firms such as Samsung and Hyundai, and expand exports of high-value-added products. They should also promote integrated models combining cross-border e-commerce, overseas warehouses, and digital settlement systems by establishing logistics hubs and overseas warehouses in cities such as Incheon and Busan to reduce transaction and logistics costs.

For second-gradient provinces such as Tianjin, improving trade efficiency requires strengthening industrial specialization and optimizing trade processes. Jiangsu and Shandong can capitalize on China-South Korea FTA cooperation demonstration zones to develop the marine economy and specialized automotive-parts trade. Establishing mutual recognition mechanisms for automotive-parts testing standards would further reduce transaction costs and trade inefficiencies. Hainan can leverage Free Trade

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Port policies to expand imports of South Korean duty-free products and exports of local agricultural products, thereby increasing bilateral trade volume.

For third-gradient inland provinces such as Henan and Hubei, efforts should focus on addressing logistics and industrial constraints. These provinces can strengthen cooperation between inland dry ports and coastal ports such as Qingdao and Lianyungang to build integrated land-sea multimodal transportation networks and reduce logistics costs. They can also undertake industrial transfers from the Yangtze River Delta and Pearl River Delta regions, attract South Korean small and medium-sized enterprises to industrial parks such as the China-Korea Industrial Park in Wuhan, and expand trade with South Korea.

For fourth-gradient provinces such as Xizang and Heilongjiang, trade potential can be enhanced through targeted assistance programs and dedicated development funds. Establishing partnership mechanisms with first-gradient provinces would allow these regions to share trade channels, logistics networks, and digital platforms. Heilongjiang can focus on the deep processing of agricultural products and leverage Suifenhe Port to integrate product traceability systems with cold-chain logistics, thereby expanding agricultural exports to South Korea. Xizang and Xinjiang can utilize China-Europe Railway Express networks to expand exports of mineral and specialty products to the South Korean market.

3.2. Enhance the Effectiveness of Key Variables and Lay a Solid Foundation for Trade Growth

With respect to economic scale and population, provinces should strengthen industrial matching with South Korean industries and leverage China's large labor force to develop integrated production models that combine labor-intensive and technology-intensive activities. Coastal provinces such as Shandong and Liaoning should deepen cooperation with South Korea's automotive-parts and shipbuilding sectors, creating employment opportunities while increasing trade value added. At the same time, the adoption of South Korean automation technologies should be encouraged to improve production efficiency and industrial competitiveness.

To mitigate the effects of geographic distance and exchange-rate fluctuations, efforts should focus on strengthening cross-regional logistics networks. Increasing shipping connections between ports such as Qingdao and Dalian and South Korean ports including Incheon and Busan would improve connectivity and reduce transportation costs. Inland provinces should accelerate the development of dry ports and integrated multimodal transportation systems linking rail, road, and maritime transport. In addition, China and South Korea should strengthen exchange-rate risk management mechanisms and encourage financial institutions to provide hedging instruments, including forward contracts and currency options, to help small and medium-sized exporters manage exchange-rate volatility and stabilize trade expectations.

3.3. Remove Inefficiency Bottlenecks and Increase Trade Facilitation

The trade inefficiency model indicates that comprehensive innovation capability is the most important factor influencing provincial trade performance with South Korea. Accordingly, governments should establish dedicated funds to support R&D talent development, technology commercialization, and patent transformation. Chinese and South Korean universities can also collaborate to establish joint innovation laboratories that promote technological cooperation and incubate trade-oriented enterprises.

FTA policies constitute the second most important factor affecting trade efficiency. Policymakers should strengthen outreach programs to improve firms' understanding and utilization of FTA provisions, provide targeted training for export-oriented small and medium-sized enterprises, and further streamline trade procedures. Coastal provinces such as Shandong and Liaoning can pilot an "FTA+bonded warehouse" model that allows imported South Korean automotive parts to be stored under bond before customs clearance, reducing inventory and financing costs for firms.

Transportation facilitation also plays an important role in reducing trade inefficiency. Efforts should focus on upgrading transportation systems and logistics infrastructure. Coastal ports should accelerate the adoption of smart-port technologies and automated container-handling systems, while inland provinces should optimize China-Europe Railway Express routes, reduce transfer requirements, and improve overall transportation efficiency.

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3.4. Establish a Long-Term Collaborative Mechanism to Realize the Potential of Trade Cooperation

The market opening environment should be further optimized. To address the finding that market openness does not significantly reduce trade inefficiency, pilot opening-up programs should be expanded in sectors such as finance, healthcare, and digital services. For example, Shanghai and Guangdong can continue exploring cross-border financial cooperation with South Korea and expand the use of RMB settlement in bilateral trade. Hainan and Yunnan can pilot greater openness in medical tourism and digital content services for the South Korean market, gradually generating long-term synergistic benefits. In addition, China-South Korea trade expos, industrial matchmaking events, and business forums should be held regularly to strengthen enterprise cooperation and promote deeper integration of industrial and supply chains across provinces and with South Korea.

Cross-provincial trade coordination platforms should also be established to facilitate the sharing of market information, policy resources, and business opportunities between eastern coastal provinces and central and western regions. Such mechanisms would help create a coordinated development pattern characterized by eastern leadership and broader regional participation. At the same time, talent development should be strengthened to support long-term trade cooperation. Universities can jointly establish or expand programs in Korean language, international trade, and related fields to cultivate professionals with expertise in China-South Korea economic and trade relations. These efforts would provide sustained human-capital support for provincial trade cooperation with South Korea and contribute to the continuous improvement of trade efficiency and high-quality trade development across China’s 31 provinces.

4. Conclusion

Based on 2014-2023 panel data of 31 Chinese provinces, this paper adopts the time-varying stochastic frontier gravity model to investigate the driving factors, trade potential and spatial heterogeneity of China’s provincial-level trade cooperation with South Korea. The empirical results show that provincial economic scale, population and comprehensive innovation capability significantly boost Sino-Korean trade, while geographical distance and RMB exchange-rate appreciation exert restraining effects. Trade inefficiency is notably reduced by comprehensive innovation capability, FTA dividends and transportation facilitation, whereas market facilitation shows no significant influence.

During the sample period, the average provincial trade efficiency with South Korea kept declining, presenting a four-layer spatial gradient from coastal open regions to inland and border areas. Nevertheless, overall trade potential kept rising, showing characteristics of “head concentration, middle-tier growth and border-region lag”. COVID-19 caused short-term trade potential correction, and RCEP implementation drove a rapid post-pandemic rebound.

To advance high-quality Sino-Korean trade cooperation, differentiated regional policies matching efficiency gradients should be implemented. It is necessary to strengthen core driving forces including innovation capacity, remove logistics and institutional bottlenecks of trade inefficiency, and build long-term collaborative mechanisms. Eastern coastal provinces should give play to their leading advantages, while inland and border provinces need to improve multi modal transport and undertake industrial transfer, so as to narrow provincial gaps and release the untapped Sino-Korean trade potential.

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