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Does institutional openness improve the trade efficiency of China's agricultural products imported from Central Asian countries? A time-varying stochastic frontier gravity model

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Introduction: Institutional openness is becoming increasingly important for agricultural trade between China and Central Asian countries.

Methods: This study employs a time-varying stochastic frontier gravity model to investigate the influence of institutional openness on the trade efficiency of China imported agricultural products from Central Asian countries under uncertainty, and further computes the import potential from 2000 to 2022.

Results: The research reveals that the impacts of different aspects of institutional openness on trade efficiency vary. Firstly, in terms of border opening measures, the joint accession to the WTO and the signing and implementation of the "Belt and Road Initiative" have effectively enhanced China's import trade of agricultural products from Central Asian countries. Secondly, regarding the impact of infrastructure, a higher efficiency of trade logistics clearance and a lower tariff are more beneficial for improving the trade efficiency. Thirdly, as for the degree of openness of the socio-economic system, a higher level of economic freedom in Central Asian countries societies are more conducive to promoting the export of agricultural products to China. Additionally, a higher uncertainty of China's economic policies may enhance the trade efficiency. However, the outbreak of the COVID19 and the Russia-Ukraine war have significantly diminished the trade efficiency. Fourthly, from 2015 to 2022, China's average export trade efficiency to Central Asian countries range from 0.3 to 0.6, with an import potential value of approximately 2.1 to 2.2 billion US dollars, indicating substantial import potential, especially for Kazakhstan and Uzbekistan.

Discussion: It is recommended to implement the "Belt and Road Initiative", enhance the logistics infrastructure, improve the efficiency of trade clearance, reduce the tariff burden on agricultural products, and stabilize the trade expectations of Central Asian countries under the unstable external economic environment, thereby enhancing the efficiency of agricultural trade between China and Central Asia countries.

KEYWORDS

Central Asian countries, uncertainty, institutional openness, agricultural trade, trade efficiency

1 Introduction

China first put forward the "Belt and Road Initiative" (BRI) in Central Asian countries. With the implementation and promotion of the BRI, the scale of agricultural trade from Central Asian countries to China has been growing continuously, from 9.9 million U.S. dollars in 2000 to 691 million U.S. dollars in 2022, with an average annual growth rate of 21.3% (Table 1). The economies of the Central Asian countries are in the process of transition, and the agricultural sector is one of the most important sectors in the five Central Asian countries, accounting for 10% ~ 45% of their GDP and employing 20% ~ 50% of total employment (Hamidov et al., 2016; Yu et al., 2020). This means that agricultural production and trade occupy a major position in its economic structure, which is related to the local livelihood. To cope the current international environment with steeply increasing in uncertainty and instability, the export trade of agricultural products between China and Central Asian countries, can effectively improve the farmers' employment and incomes in Central Asian countries, which will enhance the degree of openness in the agricultural sector and the resilience of the food system in Central Asian countries.

However, agricultural trade in Central Asian countries still faces high costs, both for geographical reasons and institutional barriers. And institutional openness is becoming increasingly important for agricultural trade (Pomfret, 2017; Sun and Zhang, 2021). In 2023, China and Central Asia countries signed the China-Central Asian countries Summit Outcome List, which proposed the need to promote the level of agricultural trade between China and Central Asian countries in terms of mechanisms and institutions. Therefore, it is of great significance to evaluates the impact of institutional openness on the efficiency of agricultural trade between China and Central Asian countries.

The research on institutional openness mainly focused on the exploration of its definition (Research Group of Institute of International Economics, National Development and Reform Commission, 2021; Zhang, 2021; Dai, 2021). Relevant studies believed that the essence of systematic opening up is the expansion, extension and deepening of "border opening up" to "internal opening up" in the past, and the formation of basic rules and systems in line with the prevailing rules of international economic and trade activities in the process of promoting rule changes and optimizing system design. In promoting rule and optimizing institution design, it forms basic rules and systems that are in line with the prevailing rules in international economic and trade activities, which is an advanced institutional arrangement that plays a leading role in the adjustment and improvement of the new round of highly standardized international economic and trade rules (Chang and Qian, 2022; Zhao and Zhang, 2022). With the deepening of the understanding of institutional openness, some researchers have also tried to sort out the characteristics of institutional openness, the mechanism and industrial chain risk, as well as the practical foundation and realization path with the Free Trade Zone (FTZ) as the core (Guo, 2022; Liu et al., 2023; Zhao and Zhang, 2022). At the same time, some studies have begun to use three dimensions of business environment, trade and investment liberalization and facilitation, and institutional innovation to measure institutional openness (Nie and Xue, 2022), as well as to quantitatively assess the impact of institutional openness on enterprise innovation (Wang and Chang, 2023). Related studies have paid less attention to institutional openness and its influence on agricultural trade (Wang and Chang, 2023).

TABLE 1 China's total imports of agricultural products from Central Asian countries (millions of dollars).

Year	Imports	Year	Imports
2000	98.74	2012	610.81
2001	20.24	2013	720.65
2002	36.96	2014	1255.76
2003	71.86	2015	1107.34
2004	73.97	2016	1440.11
2005	47.20	2017	2408.31
2006	47.74	2018	3234.62
2007	69.05	2019	4711.40
2008	38.64	2020	4994.37
2009	61.07	2021	3731.02
2010	159.08	2022	6914.32
2011	106.03	Annual rate of growth	21.3%

Calculated by the authors based on HS01-24 coded data collated from the UN Comtrade database.

With the deepening of China's economic and trade cooperation relations with Central Asian countries, the research on China's trade in agricultural products with Central Asian countries have gradually increased. Relevant studies are mainly focused on the following aspects: first, the competitiveness and complementarity of China's agricultural products trade with Central Asian countries (He et al., 2016; Jia, 2021; Liu, 2020; Li and Li, 2011; Yi and Abula, 2008). Relevant studies have shown that Central Asian countries has strong international competitiveness in the export of land-intensive products such as cotton and silk, and China has relatively strong competitiveness in technology-intensive agricultural products such as vegetables and fruits, meat, fish, and eggs, while the complementarity of bilateral trade in agricultural products has increased significantly, and the categories of agricultural products that have strong complementarities are mainly concentrated in vegetables, sugar, flour products, and textile fibers of the cotton category (Meng, 2018). Secondly, China's trade with Central Asian countries in agricultural products is growing. The study on the growth drivers of agricultural trade between China and Central Asian countries (Gong and Zhang, 2014; Hong, 2019; Zhu et al., 2018; Guo et al., 2021). These studies point out that the growth of market demand is the primary reason for the growth of agricultural trade. Third, the potential and efficiency of agricultural trade between China and Central Asian countries (Lv et al., 2020; Qi, 2019; Tan et al., 2016; Wumuer, 2016) and trade structure studies (Yan et al., 2021). Relevant studies have shown that the trade in agricultural products between Central Asian countries and China has a high potential. Fourth, there are studies are about China and Central Asian countries' agricultural trade patterns (Chen, 2014; Li, 2018), trade costs (Hou and Abula, 2015), trade facilitation (Felipe and Kumar, 2014; Hu, 2014; Kai et al., 2021; Yu, 2022; Yu, 2020), FTA construction (Wang et al., 2019), trade margins (Fang and Li, 2023), and supply chain performance evaluation (Abula, 2022). Fifthly, rising studies focused on agricultural value chains and infrastructure in Central Asian countries (Pomfret, 2014; Pomfret, 2017), soil and water resource use

efficiency (Liu et al., 2021), virtual soil and water trade (Zhou et al., 2022), water resource use and food system relationships (Ma et al., 2022), trade openness and food security, and trade openness and food security (Sun and Zhang, 2021).

Compared with existing studies, this study has three notable contributions. First, previous research on institutional openness mainly focused on its connotation, however, how to measure institutional openness has not formed a unified standard. Our study contributes by measuring institutional openness with multiple indicators as comprehensively as possible. Secondly, there are many existing studies on the potential and efficiency of agricultural trade in Central Asian countries, but more on the impact of trade facilitation and less on the efficiency of agricultural trade from the perspective of institutional openness. This study focuses on the impact of institutional openness on the efficiency of agricultural trade in Central Asian countries, which can fill the lack of research in this area. Third, fewer studies have considered the impact of uncertainty risks such as the Russia-Ukraine war and the Covid-19 on agricultural trade between China and Central Asian countries. Instead, this study considers it. Therefore, this study tries to adopt suitable indicators to quantitatively measure the institutional openness, and assesses its impact on the efficiency of China's agricultural trade with Central Asian countries under the background of uncertainty based on UN Comtrade database from 2000 to 2022. This study will provide policy references for improving the efficiency of agricultural trade between China and Central Asian countries.

The rest of this research is constructed as follows. Section 2 describes the material and methods, we provide detailed information about the data sources and data structure; the time-varying stochastic frontier gravity model of trade and the estimation techniques involved in the analysis. Section 3 presents and discusses the estimated results under study. All the findings of the study are concluded in Section 4 of this study.

2 Materials and methods

In this section, we present how we conducted this study and the tools we used. First, we explain the basic idea of the Stochastic Frontier Gravity Theory equation. Second, we describe our derived model for the agriculture exports from Central Asian countries, and give information about the data source and summarize the main characteristics of the data. Finally, we provide the detailed protocol involved in the estimation of our model.

2.1 Time-varying stochastic frontier gravity model

This paper intends to use a stochastic frontier gravity model to investigate the impact of institutional openness on the trade efficiency of China's imports of agricultural products from Central Asian countries. The traditional gravity model does not take into account the influence of policy factors, such as institutional factors and other subjective factors, which means the trade potential it calculates does not truly reflect the trade potential between countries. To solve this problem, the stochastic frontier gravity model was introduced into the field of trade research. The stochastic frontier production function first originated from the concept of technical efficiency proposed by Farrell (1957) and Lebenstein (1966), Aigner et al. (1977) and Meeusen and Van Den Broeck (1977) subsequently used the stochastic frontier model to analyse the technical efficiency of the production function. Since the traditional trade model is essentially similar to the production function, Armstrong (2007) argues that it is equally feasible to use the stochastic production function to analyse trade efficiency, providing a theoretical basis for the stochastic frontier gravity model to study trade efficiency. As the stochastic frontier gravity model takes into account the technical inefficiency term, it is more scientific than the traditional gravity model, and has been widely used in the field of trade. According to the theoretical setting of Aigner et al. (1977), Meeusen and Van Den Broeck (1977) and Armstrong (2007), the general form of the stochastic frontier gravity model is as follows (Equations 1–3):

$$T_{ijt} = f\left(x_{ijt}\beta\right)e^{\left(v_{it}-u_{it}\right)} \tag{1}$$

$$T_{ijt}{}^{*} = f\left(x_{ijt}\beta\right)e^{\left(v_{it}\right)} \tag{2}$$

$$TE_{ijt} = \frac{T_{ijt}}{T_{ijt}{}^{*}} = e^{\left(-u_{it}\right)} \tag{3}$$

In Equation 1 where T_{ijt} represents the actual trade value between country i and country j, and $T_{ijt}{}^{*}$ in Equation 2 represents the trade potential value between country i and country j under the ideal condition, i.e., the maximum trade value under the frontier condition, where all the trade inefficiencies are overcome. x_{ijt} is a vector of order 1*k, which represents the natural factors affecting the trade value, such as gross domestic product (GDP), population, and geographic distance, etc., and β is the parameter to be evaluated parameters. v_{it} is the random error term and u_{it} is the trade inefficiency term, where TE_{ijt} in Equation 3 is the trade efficiency value, which is the ratio of the actual trade value and the trade potential value. The size of this value can be used to judge whether the trade is efficient or not, when the value is 1, it indicates that there is no trade inefficiency, the two sides of the trade has reached the maximum frontier value, the trade potential is fully tapped; when the value is 0, it indicates that the trade friction between the two sides of the trade reaches the maximum value so that the two sides cannot trade, and the trade potential that can be tapped in the future reaches the maximum; when the TE $\in$ (0,1), it indicates that there are trade inefficiencies. In specific empirical evidence, generally take the logarithm of both sides of Equation 1 to get the following Equation 4:

$$lnT_{ijt} = lnf\left(x_{ijt}\beta\right) + v_{it} - u_{it} \tag{4}$$

In order to explore the influencing factors of trade inefficiency, this paper draws on the one-step method proposed by Battese and Coelli (1995) to estimate trade inefficiency by regressing the stochastic frontier model and the trade inefficiency model simultaneously. The

theoretical equations for the stochastic frontier gravity model and the trade inefficiency model are given in the following Equations 5 and 6:

$$u_{it} = \left(\alpha z_{it} + \varepsilon_{it}\right) \tag{5}$$

$$lnT_{ijt} = lnf\left(x_{ijt}\beta\right) + v_{it} - \left(\alpha z_{it} + \varepsilon_{it}\right) \tag{6}$$

where z_{it} represents the factors affecting trade inefficiency and α is the parameter to be estimated for the factors affecting trade inefficiency. v_{it} and u_{it} are independent of each other, and u_{it} obeys a truncated normal distribution.

Since the data in this paper belongs to inter-period panel data, in order to accurately measure whether the trade efficiency of China's imported agricultural countries changes over time, this paper draws on the research of Cornwell et al. (1990) and introduces time-varying factors into the stochastic frontier gravity model, whose expression is:

$$u_{ijt} = \left\{\exp\left[-\eta\left(t - T\right)\right]\right\} u_{ij} \tag{7}$$

In Equation 7 where u_{ijt} represents the trade inefficiency term, T denotes the number of observation periods, and η is the time effect parameter to be estimated, which is the eigenvalue that characterizes whether trade efficiency changes. When η>0, it means that the technical inefficiency increases over time, the trade potential is suppressed, and the trade efficiency decreases; η<0 means that the trade inefficiency decreases over time, i.e., the trade potential is gradually released, and the trade efficiency increases; η=0 means that the technical inefficiency term does not change over time, and a time-invariant model should be used at this time.

2.2 The model and data

We constructed a time-varying stochastic frontier gravity model based on Equation 5 as follows:

$$\begin{aligned} lnT_{ijt} &= \beta_0 + \beta_1 \ln \mathrm{GDP}_{it} + \beta_2 \ln \mathrm{GDP}_{jt} + \beta_3 \ln \mathrm{POP}_{it} \\ &+ \beta_4 \ln \mathrm{POP}_{jt} + \beta_5 \ln \mathrm{DIS}_{ijt} + \beta_6 CONTIG_{ijt} + \beta_7 land_{it} \\ &+ \beta_8 AGR_{it} + v_{it} \end{aligned} \tag{8}$$

In Equation 8, T_{ijt} is explanatory variable, representing the amount of agricultural exports from China j to Central Asian country i in period t. The right side of the equation is the explanatory variable. Among them, GDP_{it} and GDP_{jt} are the real GDP (2015 constant dollar statistical caliber) of China and the import source country, which measures the level of economic development and the living standard of the residents, and the data are soured from the World Bank's World Development Indicators (WDI) database. POP_{it} and POP_{jt} represent the population sizes of the import source country and China, which measures the domestic market demand, and it is usually considered that the larger the population out of the importing source country, the larger the domestic market demand and the larger the imports are likely to be, whereas the larger the population in the exporting country, the larger the domestic demand and the smaller the exports, data from WDI. $\ln \mathrm{DIS}_{ijt}$ represents the logarithm of the distance between the two countries utilizing their capitals, and it is generally considered that the greater the distance, the greater the transportation costs, which will reduce trade between the two countries, data from the database of the CEPII. $CONTIG_{ijt}$ represents whether Central Asian countries border with China, if yes, it is 1, otherwise it is 0, this data is also from CEPII. $land_{it}$ measures the per capita arable land area of the exporting country, which measures the agricultural arable land resources of the exporting country, in general, the more abundant the arable land resources are, the higher the possibility of exporting agricultural products (Edison, 2021), this data is from WDI. AGR_{it} is the share of value added of agricultural industry in the total GDP of the exporting country, which measures the degree of abundance of agricultural resource endowment of the exporting country, and it is generally believed that the more abundant the agricultural resources, the higher the possibility of agricultural products export, and the data is sourced from WDI.

In order to further explore the impact of institutional openness on trade inefficiency, this paper constructed a trade inefficiency model that includes institutional openness measurement index system as follows:

$$\begin{aligned} u_{it} &= (\alpha_0 + \alpha_1 WTO + \alpha_2 BRI + \alpha_4 logis_{it} + \alpha_5 MFN_{it} \\ &+ \alpha_6 freedom_{it} + \alpha_7 freedom_{jt} + \alpha_8 uncertainty_{jt} \\ &+ \alpha_9 conflict_{jt} + COVID19 + \varepsilon_{it}) \end{aligned} \tag{9}$$

According to existing studies, institutional openness has rich connotations, including not only the traditional "border opening" based on the signing of relevant trade agreements, but also the deepening of "domestic opening" based on the optimization of institutional rules. Therefore, in order to comprehensively measure the institutional openness, we constructed the relevant indicator system from the following four aspects in Equation 9:

First, trade "border openness" indicators included two main indicators: WTO represents whether the trading country joins the WTO or not, with a value of 1 for yes and 0 for no. Studies have shown that joining the WTO is effective in stabilizing trade relations (Guo et al., 2015). BRI represents whether countries join the Belt and Road Initiative (BRI), which takes the value of 1, otherwise it takes the value of 0. Existing studies show that BRI can effectively promote agricultural trade (Zhao et al., 2024). So the signing of the BRI may improve the efficiency of China's agricultural import trade with Central Asian countries. This paper utilizes WTO and BRI to measure the degree of openness of the trade regimes of the two countries.

Secondly, the agricultural trade environment mainly contains: $logis_{it}$ and $logis_{jt}$ are the trade clearance efficiency indexes of country i and China (j) respectively, which are derived from the efficiency of customs clearance procedures in the World Bank's Digital Logistics Performance Index (DLPI). And the values are from 1–5, with 1 representing very low and 5 representing very high. Because agricultural products are not easy to be preserved, the clearance time of international agricultural trade has a great influence on the trade efficiency of agricultural products, and this index can effectively

TABLE 2 Descriptive statistics.

Variable	Definition	Mean	Std. dev.	Min	Max
$\ln GDP_i$	Ln GDP of exporting country *i*	23.888	1.482	21.716	26.124
$\ln GDP_j$	In GDP of China	29.648	0.564	28.650	30.424
$\ln POP_i$	Ln population size of exporting country *i*	16.310	0.655	15.404	17.389
$\ln POP_j$	Ln China's population	21.020	0.036	20.956	21.069
$\ln DIS_{ij}$	Ln the distance between the two capitals	8.236	0.062	8.152	8.307
$CONTIG_{ijt}$	Adjacency of the border between the two countries	0.750	0.435	0	1
$land_{it}$	Cultivated land per capita (ha/person)	0.560	0.703	0.088	2.026
AGR_{it}	Share of agricultural GDP of exporting countries (%)	18.630	9.132	4.288	34.541
WTO	Accession to WTO (yes = 1, no = 0)	0.446	0.500	0	1
BRI	Whether or not signed the Belt and Road Initiative (Yes = 1, No = 0)	0.304	0.463	0	1
$logis_{it}$	Efficiency of trade clearance procedures in exporting countries i	2.174	0.28	1.800	2.750
MFN_{it}	Weighted average most-favored-nation (MFN) tax rate for country *i* (%)	6.456	2.777	1.910	17.500
$freedom_{it}$	Economic freedom in country *i*	55.023	7.381	38.100	71.100
$freedom_{jt}$	China's economic freedom	53.709	2.823	48.000	59.500
$uncertainty_{it}$	Ln of the Chinese Economic Policy Uncertainty Index	141.258	106.706	35.566	390.388
$conflict_{it}$	Whether or not a Russo-Ukrainian war broke out (Yes = 1, No = 0)	0.043	0.205	0	1
Covid-19	Whether or not there is an outbreak of Covid-19(Yes = 1, No = 0)	0.130	0.339	0	1

"std.dev." means standard deviation.

measure the trade facilitation degree of agricultural trade, which is an important part of system-oriented opening. These trade facilitation measures related to procedures can profoundly affect agricultural trade (Fu et al., 2023). MFN_{it} is the most favored nation (MFN)-weighted average tax rate of country *i*. This index can effectively measure the trade tax burden of agricultural trade, which sourced from WDI.

Thirdly, we used economic freedom to measure the degree of openness of socio-economic system. $freedom_{it}$ and $freedom_{jt}$ represent the degree of economic freedom of country i and China (j) respectively, which is obtained from the Heritage Foundation Database, with a value range of 0–100. The higher the score indicates a better evaluation of the indicator, which exogenously measures the socio-economic system and the degree of openness of the importing source country from different dimensions (Pan and Fu, 2018), including the degree of protection of property rights, the degree of governmental economic intervention, judicial efficiency, governmental fiscal expenditure, commercial freedom, labour freedom, monetary freedom, trade freedom, investment freedom, and financial freedom, etc. The degree of openness in all aspects of the social system.

Fourth, regarding the stability of the external environment, supply chain disruption caused by external policy environment will have a negative impact on agricultural trade (Cao et al., 2020), the external policy environment's changes may have a greater impact on the efficiency of agricultural trade. So this study cheese three variables to capture the stability of the external environment. $uncertainty_{jt}$ represents China's economic policy uncertainty index, data from http://www.policyuncertainty.com/. The Economic Policy Uncertainty Index (EPU), developed by Baker et al. (2015), is a standardized index of the number of articles related to economic policy uncertainty in China's mainstream newspapers, which is used to reflect China's economic and policy uncertainty. And we also investigated the impact of the Russian-Ukrainian war ($conflict_{jt}$) and Covid19 ($COVID19$).

The descriptive statistics and expected direction of action of all the above variables are shown in Table 2.

2.3 Estimation protocol

It is necessary to choose an appropriate functional form before utilizing the stochastic frontier gravity model. The test consists of two steps: the first one is to test the existence of trade inefficiency; the other is to test whether trade inefficiency changes over time. As shown in Table 3, the LR statistic is 74.353, which rejects the original hypothesis of "there is no trade inefficiency" at 1% significance level, indicating that there existed trade inefficiency in the model and it's suitable for adopting the stochastic frontier gravity model. The time-varying test result shows that the LR statistic is 56.521, which rejects the original hypothesis of "trade inefficiency does not change over time" at 1% significance level, i.e., $\eta = 0$ is not valid, indicating that trade inefficiency changes over time, and it is more

TABLE 3 Stochastic frontier gravity model hypothesis testing.

Original hypothesis	Unconstrained model	Constrained model	LR statistic	1% Critical value	Test conclusion
No trade inefficiency: $\gamma = \mu = \eta = 0$	−244.87	−207.67	74.353	10.501	Rejected
No change in trade inefficiency: $\eta = 0$	−238.41	−210.15	56.521	8.273	Rejected

Compiled from Frontier 4.1 regressions.

TABLE 4 Regression results of the non-efficiency model.

Variable	Coefficient	Std. dev.	T-value	Variable	Coefficient	Std. dev.	T-value
Constant	−7545.156***	1.004	−7515.509	Constant	3.894	1.558	2.500
$\ln GDP_{it}$	12.717***	0.667	19.076	WTO	−2.939***	1.150	−2.556
$\ln GDP_{jt}$	−43.999***	1.866	−23.577	BRI	−8.852***	1.525	−5.806
$\ln POP_{it}$	−91.132***	1.080	−84.359	$logis_{it}$	−9.457***	2.066	−4.577
$\ln POP_{jt}$	418.012***	2.133	196.015	MFN_{it}	2.317***	0.358	6.464
$\ln DIS_{ijt}$	153.665***	1.211	126.936	$freedom_{it}$	−0.799***	0.176	−4.538
$CONTIG_{ijt}$	−95.180***	1.480	−64.290	$freedom_{jt}$	0.077	0.180	0.426
$land_{ijt}$	36.762***	1.225	30.008	*uncertainty -jt*	−0.095***	0.022	−4.316
AGR_{it}	0.314***	0.074	4.255	$conflict_{it}$	13.020***	2.684	4.850
t	3.118***	0.140	22.277	*COVID-19*	11.121***	2.118	5.252
				δ2	16.552***	1.878	8.813
–	–	–	–	γ	0.788***	0.058	13.548
Log Likelihood	−209.232						
LR test	58.352						

Obtained by collating results from Frontier 4.1, *, **, and *** indicate significance levels at 10, 5, and 1%, respectively.

appropriate to use time-varying stochastic frontier gravity model.

3 Results and discussion

3.1 Results

Table 4 shows the estimation results of the time-varying stochastic frontier gravity model and the trade inefficiency model using the "one-step" regression. The value of γ is 0.768, which indicates that the trade inefficiency model captures the trade inefficiency information comprehensively. According to the regression results, it can be found:

In the stochastic frontier gravity model, the coefficient of $\ln GDP_{it}$ was positive and significant indicating that the higher the GDP of the export source country could improve the agricultural trade with China. It may be due to the fact that the higher the economic development level of the exporting country has abilities to increase the export of agricultural products accordingly. The significant negative coefficient of $\ln GDP_{jt}$ indicated that the higher the GDP of China have the higher the demand for agricultural products, and the less reliance on Central Asian countries were. The impact of $\ln POP_{it}$ was significantly negative, indicating that the higher the population of the export source country, the higher its domestic consumption of agricultural products, the more unfavourable for exporting agricultural products. The coefficient of $\ln POP_{jt}$ was significantly positive, indicating that the higher the population of China, which promotes imports. The coefficient of $\ln DIS_{ijt}$ was significantly negative, which indicated that the higher the trade and transportation cost was, and the more unfavourable it was for China to import agricultural products from Central Asian countries. And the result was consistent with the existing studies (Fu et al., 2023). The impact of $CONTIG_{ijt}$ was significant negative, it's because that the transportation cost was higher when China imported agricultural products from Central Asian countries mainly through land transportation compared to sea transportation. The coefficients of $land_{ijt}$ and AGR_{it} were significantly positive, which implied that the land resources and agricultural endowment of Central Asian countries are more abundant, the they are more favourable for exporting agricultural products to China.

In the trade inefficiency model, considering the trade "border opening": First, the coefficient of WTO was-2.942, which was significantly negative at the 1% significance level. It indicated that the exporters to join the WTO can significantly promote China's imports of agricultural products from Central Asian countries. China's accession to the WTO in 2001, if exporters is also a member of the

WTO, which meant that both sides need to comply with the WTO's rules of free trade. And the trading countries on both sides of the automatic access to MFN, which eliminates the trade inefficiency in favour of China's imports of agricultural products. This is consistent with the research conclusions of previous research, which shows the joint accession of countries to the WTO is an institutional arrangement that effectively enhances the trade efficiency of both sides (Guo et al., 2015). Second, the impact of BRI on trade inefficiency was negative and significant, which indicated that the signing of the BRI agreement between China and Central Asian countries had reduced trade inefficiency and promote China's imports of agricultural products from Central Asia countries (Zhao et al., 2024). It is mainly due to the fact that BRI can enhance facility connectivity, trade flows, financial integration, policy communication and people-to-people ties, which highlighted the mutually beneficial nature of BRI in agricultural trade (Liu and Xu, 2025).

Secondly, regarding the impact of agricultural trade environment, the coefficient of $logis_{it}$ was significantly negative, which expressed that the higher the efficiency of China's trade clearance with Central Asian countries, the more it could reduce the inefficiency of agricultural trade. And the coefficient of MFN_{it} was also significantly positive, which indicated that the lighter the tax burden of agricultural trade between the two sides of the trade, the more trade inefficiency can be reduced.

Third, regarding the degree of openness of socio-economic system, the coefficient of $freedom_{it}$ was significantly negative for Central Asian countries, which implied that the higher economic freedom of Central Asian countries may reduce trade inefficiency, i.e., increase trade efficiency (Siddika and Ahmad, 2022). Whereas, the coefficient of $freedom_{jt}$ for China was positive and insignificant, which meant that the higher the economic freedom of China, the more likely it was to import agricultural products from the rest of the world, and thus may reduce its dependence on Central Asia countries market.

Fourth, regarding the stability of the external environment, China's economic policy uncertainty index $uncertainty_{jt}$ was significantly positive, which implied that when China's economic faced higher policy uncertainty, it could reduce the inefficiency of agricultural trade. The reason is that when there was a big change in the external policy environment, in order to ensure the stability of China's domestic supply of agricultural products, China would increase the import of agricultural products from Central Asian countries. And the impact of Russia-Ukraine war $conflic_{it}$ was significantly positive, which indicated that the outbreak of Russia-Ukraine war has lowered the efficiency of Central Asian countries in exporting agricultural products to China. The Russian-Ukrainian war and the outbreak of *COVID19* significantly reduced the efficiency of Central Asian countries in exporting agricultural products to China, which is in line with the judgment of existing studies that *COVID19* would have a negative impact on agricultural trade (Miao et al., 2024).

3.2 Trade efficiency and trade potential

Based on the previous results, we further analysed the trade efficiency and trade potential of China's agricultural products imported from Central Asian countries. Figure 1 shows the average trade efficiency of China's agricultural products imported from Central Asian countries from 2000 to 2022. The overall trade efficiency fluctuates greatly, and the overall change trend of Kazakhstan, Kyrgyzstan and Tajikistan tends to be consistent. Among them, there were several important points in time that are worth paying attention to: first, during the period of 2002–2005, China's trade efficiency towards Central Asian countries showed a downward trend. It is mainly because China's accession to the WTO in November 2001 has led to an increase in trade potential value, while the actual trade value has increased slowly in the short term, resulting in a sudden decrease in trade efficiency. And it also meant that the value of the trade potential has become larger. From 2005 to 2012, the stable trade

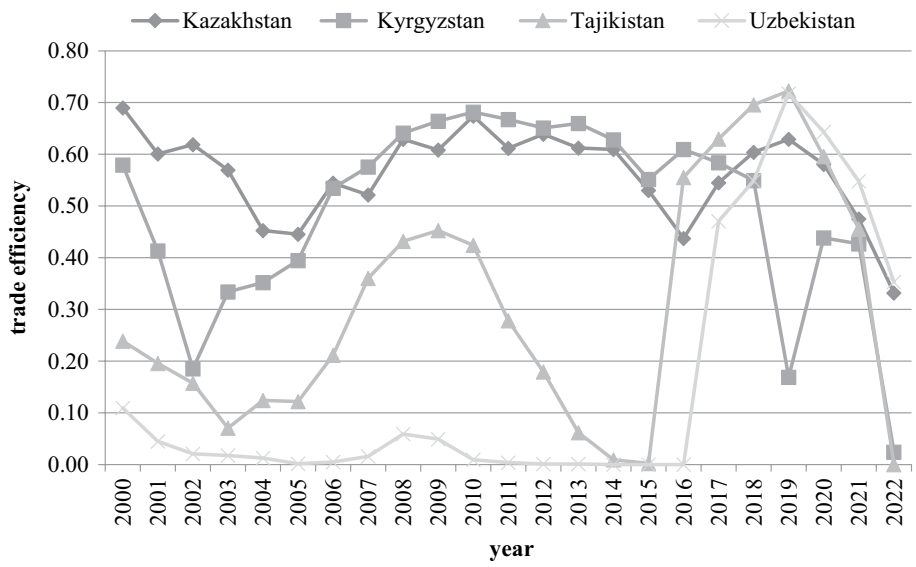

FIGURE 1
Trade efficiency of China's agricultural products imported from Central Asian countries from 2000 to 2022.

environment made the import trade efficiency rise. After the "Belt and Road" initiative was put forward in 2013, the open trade environment also improved trade potential value, and reduced the trade efficiency, which meant the trade potential value went up to a new level. From 2020 to 2022, with the outbreak of the COVID19 and the Russia-Ukraine war, the trade efficiency value was low, which also meant that the trade potential value became larger. During the period, the trade efficiency of both sides fluctuated greatly, from the current 0.6 ~ 0.7 to about 0.3 ~ 0.4. The changes in Uzbekistan and Tajikistan were more pronounced, because the two countries with a lower degree of economic development have been more affected by the frequent occurrence of international uncertainty risk events. In particular, it should be noted that in Figure 1, the zero value of Uzbekistan's trade potential for the period 2010–2015 is due to the fact that Uzbekistan's trade with China was zero during the same period.

In terms of trade potential, there is still more room for China to import agricultural products from Central Asian countries. According to Table 5, China imported a total of $591 million from Central Asian countries in 2022, with an overall trade efficiency of 0.325 and a trade potential value of $2.126 billion, which means that nearly 70% of the trade potential remains to be realized. As for countries, the trade efficiency of Kazakhstan and Uzbekistan were 0.332 and 0.353 respectively, Tajikistan was 0.024, while Kyrgyzstan was zero in 2022. To avoid the bias of a single year on the measurement of trade efficiency, this paper progressed to measure the average trade efficiency of each country in 2015–2022. The results shown that Kazakhstan, Tajikistan, Kazakhstan, Tajikistan, Kyrgyzstan and Uzbekistan were 0.474, 0.294, 0.591 and 0.504, respectively. And the average value of trade potential calculated accordingly was 762 million dollars and the highest value of trade potential is 2.21 billion dollars. In summary, the highest trade potential of China's trade with Central Asian countries is less than 60%, and the lowest is only 30%, with a trade potential value of between 2.1 ~ 2.2 billion USD. Assuming that the trade potential is fully realized, China's trade potential for agricultural products imported from Central Asian countries could increase by 2.1 ~ 2.2 times on the current basis. It indicated that the trade prospects will be very broad between China and Central Asian countries. Among them, Kazakhstan and Uzbekistan are the key countries, and Tajikistan, Kyrgyzstan and Turkmenistan need larger agricultural investment and cooperation in order to fully realize the trade potential.

4 Conclusion and policy implications

Based on the data of UN Comtrade database from 2000 to 2022, this study employed a time-varying stochastic frontier gravity model to investigate the impact of institutional openness on China's trade efficiency of agricultural products imported from Central Asian countries in the context of uncertainty, and finally measured the trade efficiency and trade potential of China's imports of agricultural products from Central Asian countries. The following conclusions can be drawn from the above analysis.

Firstly, China's agricultural imports from Central Asian countries will have a lot of room for growth. As mentioned above, during the period 2001 ~ 2022, the scale of China's agricultural imports from Central Asia countries grew from less than US$10 million to US$690 million, maintaining a superb average annual growth rate of 21.3%. And China's average export trade efficiency to Central Asian countries for 2015 ~ 2022 is between 0.3 and 0.6, and the import potential is about $2.1–2.2 billion, indicating that 60% ~ 70% of the trade potential can still be tapped, and there is a large import potential.

Secondly, institutional openness could improve the trade efficiency in generally of China's imports of agricultural products from Central Asian countries. As for border opening, the signing and implementation of the WTO and the BRI have effectively promoted China's trade in agricultural products imported from Central Asia countries, which suggests that border opening such as the signing of preferential trade agreements contributes to improved trade efficiency. As for trade environment, the higher the efficiency of the trade logistics and customs clearance, and the lower the most favoured MFN, the more conducive to improving the trade efficiency of China's imports of Central Asia agricultural products. Considering the socio-economic system, the higher the trade freedom of the Central Asia countries societies, the more conducive to promoting the export of agricultural products to China.

Thirdly, uncertainties such as the COVID19 and Russo-Ukrainian war have reduced the scale of imports. However, when China's economic policies face higher uncertainty risk, China would increase in importing agricultural products from Central Asian countries, which would promote the trade efficiency.

Based on these conclusions, several suggestions can be made. In order to promote the efficiency of China's agricultural imports

TABLE 5 China's trade potential in agricultural products imported from Central Asian countries.

Year	Kazakhstan	Tajikistan	Kyrgyzstan	Uzbekistan	Total
Trade efficiency					
2022	0.332	0.024	0.000	0.353	–
Average 2015–2022	0.474	0.294	0.591	0.504	–
Imports (millions of dollars)					
2022	545.3	1.8	0.0	144.3	691.4
Average 2015–2022	265.89	14.86	1.11	74.91	356.8
Import potential (millions of dollars)					
2022	1642.5	75.0	0.0	408.5	2126.0
Average 2015–2022	561.2	50.5	1.9	148.7	762.3
Maximum 2015–2022	1642.5	152.6	6.7	408.5	2210.4

Author's measurements based on regression results.

to Central Asian countries, both countries should focus on the following aspects of institutional openness: firstly, from the viewpoint of liberalization measures of the trade system, joining international organizations (such as the WTO) to jointly promote free trade, actively and steadily extending the duration of the free trade agreement, and accelerating the implementation of the BRI and other agreements on agricultural products, can effectively promote the efficiency of China's agricultural import. Secondly, as for the infrastructure of agricultural trade, our government should take relevant measures to cooperate with partner countries in many fields such as seeds, fertilizers, agricultural machinery, port transportation, etc. Specifically, to improve the logistics infrastructure, to increase the clearance efficiency of the trade, to lower the burden of taxes on agricultural products, and to improve their agricultural production capacity and export capacity are very feasible measures. Thirdly, in the case of unstable external economic environment risks, China should establish medium- to long-term procurement agreements or develop regional agricultural early-warning and coordination mechanisms with Central Asian countries in advance to stabilize the trade expectations, so as to enhance the trade efficiency in a targeted manner, which will further strengthen the cooperation and opening up of the agricultural field through the trade of agricultural products.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: UN Comtrade.

Author contributions

FC: Writing – original draft, Writing – review & editing, Validation, Data curation. XL: Resources, Conceptualization, Writing – review & editing, Funding acquisition, Supervision. ZZ: Validation, Writing – review & editing, Resources.

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Conflict of interest

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

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Correction note

A correction has been made to this article. Details can be found at: 10.3389/fsufs.2025.1645833.

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