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Article

Research on the Potential of China's Export of Edible Fungus Products to ASEAN

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Abstract: With the rapid development of China's agriculture, edible fungus products have been highlighted in the trade as it occupies an important position owing to their diverse advantages. The "Belt and Road" initiative and the construction of the "China-ASEAN Free Trade Area" promote the bilateral trade between China and ASEAN, which requires studying the potential of exporting Chinese edible fungus products to ASEAN. Therefore, the current situation and existing problems of the export of fungus products were explored in three dimensions: trade scale, product type, and country structure. The panel data from 9 countries (China and ASEAN countries) from 2003 to 2022 was analyzed using the Stochastic Frontier Gravity Model to investigate factors affecting the export volume and potential of edible fungus products. The spatial value of trade potential was estimated and suggestions were made for Chinese edible fungus products exported to ASEAN.

Keywords: ASEAN, Export potential, Edible fungus, Stochastic frontier gravity model

1. Introduction

The free trade agreement (FTA) between China and ASEAN has helped to develop the economy and trade between the two parties and increase their trade. Recently, the global economy and trade have been hit by COVID-19, the energy crisis, and high interest rates. Since 2020, ASEAN has become China's largest trading partner surpassing the EU, and in the first three quarters of 2023, it showed the resilience and potential of economic rebound. As a major agricultural country, China's edible fungus is an important product exported to ASEAN. As a healthy and nutritious agricultural product, edible fungi have high nutritional and medicinal value. Fungi export is a pillar of China's rural economy. With abundant natural resources and advanced agricultural technology, China is the world's largest producer of edible fungi with a complete industrial chain of production, processing, and sales. Scientific and technological research and development have been supporting exporting it to ASEAN. The annual production of edible fungi in China reaches more than 40 million tons, and the total annual revenue exceeds USD 42 billion according to the China Edible Fungi Association. At present, China's fungus production accounts for more than 75% of global production, and its export volume is the biggest in the global market. The economy of ASEAN, As China's main export partner for edible fungi, continues to grow, and the demand for high-quality varieties of edible fungi is increasing. In the past, most research on the economy and trade between China and ASEAN focused on the service industry and agriculture, and there were few studies on the trade of edible fungus products, especially the empirical research on the export structure of edible fungus products to ASEAN countries. Most scholars focus on the competitiveness of exported products and have little research on trade potential. Thus, it is required to research the export of edible fungi focusing on Chinese export in the global market and its competitiveness, potential, and efficiency of trading, and estimate market concentration and dependence. It is also important to understand trade potential and values for future development in trade. Based on the existing research and data, the effect of currency exchange rates on the export of fungi products was studied in this research. 20-year data was collected and analyzed using the stochastic frontier gravity model (SFGM). The result of this research can be used to estimate China's export potential of edible fungus products to ASEAN.

2. Literature Review

Edible fungi are commonly known as mushrooms and are various in size. There are more than 2,000 edible species in the world, of which about 50 species are cultured on a large scale. At present, more than 350 species of edible fungi are found in China, including shiitake mushroom, enoki mushroom, lion's mane mushroom, *Ganoderma lucidum* (Lingzhi), and *Cordyceps sinensis* (caterpillar fungus). Edible fungi are defined by the Standard International Trade Classification (SITC) and the Harmonized Commodity Description and Coding System (HS). Xue *et al*. (2017) divided edible fungus products into four categories: fresh and refrigerated, salted and temporarily preserved, dried and canned. Table 1 lists the product names and HS codes corresponding to each category.

Table 1. Classification and HS code of edible fungus products.

Category name	Product name	HS code
Fresh and refrigerated	Mushrooms of the genus Agaricus, fresh or chilled	070951
	Truffles and mushrooms and other vegetables	070959
Salted and temporarily preserved	White mushroom in brine; Other Mushrooms of the genus Agaricus in brine; Other Mushrooms of the genus Agaricus, provisionally preserved	071151
	Sungmo in brine; Shiitake mushroom in brine; Other mushroom and truffles in brine, not the genus Agaricus, Shiitake mushroom provisionally preserved by sulfur dioxide gas or in other preservative solutions; Mushrooms and truffles provisionally preserved by sulfur dioxide gas or in other preservative solutions	071159
Dry	Dried Mushrooms of the genus Agaricus	071231
	Dried Wood ears	071232
	Dried Jelly fungi (Tremella spp.)	071233
	Dried Shiitake; Dried Winter mushroom; Dried Paddy straw mushroom; Dried *Tricholoma mongolicum* Imai; Dried Boletus; Dried sungmo; Other dry mushrooms and truffles	071239
Canned	Small white agaric in air-tight containers, prepared or preserved otherwise than by vinegar or acetic acid; Other mushrooms in air-tight containers, prepared or preserved otherwise than by vinegar or acetic acid; Other mushrooms, prepared or preserved otherwise than by vinegar or acetic acid	200310
	Shiitake and other shiitake, canned, prepared or preserved otherwise than by vinegar or acetic acid	200390

Sources: Edible fungi are defined by the Standard International Trade Classification (SITC) and the Harmonized Commodity Description and Coding System (HS).

Armstrong (2007) defined trade efficiency as the degree to which the potential of trade is realized. The trade efficiency is between 0 and 1, and the value refers to the proportional relationship between the actual and optimal values of exports. The higher the trade efficiency value, the more trade potential is, reflecting the realistic level and efficiency of trade. When there is no trade inefficiency, the export trade efficiency value reaches 1, and the actual export value is just equal to the optimal export value. When there is any trade inefficiency, the export trade efficiency becomes less than 1. The greater the trade inefficiency, the smaller the trade efficiency. Trade potential is the optimal value of trade after excluding the actual trade resistance: the maximum traded value. The room for the improvement of trade potential is the difference between the optimal and the actual trade values.

In the export of edible fungus products in China, most scholars have focused on the export trade scale, production structure, and influencing factors of products. China's edible fungus products face many problems, and the trade structure needs to be optimized and improved. Peng (2020) analyzed China's edible fungus export from 2004 to 2018 using the Principal Component Analysis and Gray Prediction Method and concluded that the export price of edible fungus products, China's GDP, and total agricultural output value affected the export of edible fungus. He predicted that exports showed a fluctuation from 2019 to 2024. These results indicated deficiencies in the development of edible fungi products in China, and the stability of its export was required. Yan and Wu (2022) analyzed the characteristics of China's edible fungus export from 2008 to 2020 by measuring international competitiveness. They found that China's edible fungi trade was concentrated in Thailand, Vietnam, Malaysia, and other countries closely related. Qin *et al*. (2022) analyzed the characteristics of China's edible fungus exports from 2002 to 2020 using a constant market share (CMS) model to study the impact of demand from the Regional Comprehensive Economic Partnership (RCEP) countries on the export competitiveness of China's edible fungus. Wang *et al*. (2023) used Revealed Comparative Advantage (RCA), trade intensity index (TII), and trade complementarity index (TCI) to analyze the export volume and value of China's edible fungus products to ASEAN from 2002 to 2021 and estimated the competitiveness and potential of exports by studying the export structure and the corresponding import structure of ASEAN countries.

In the research on the measurement of trade efficiency and potential, scholars used the traditional Gravity Model to calculate the trade value and the fitting conditional mean as the trade potential index. He *et al*. (2016) used the RCA and TCI and found a strong complementarity in the trade of agricultural products between China and ASEAN countries, especially Indonesia, Vietnam, Thailand, and Malaysia, and the advantages of agricultural products. Due to the bias in the results of cross-sectional data regression, scholars have used panel data adding more explanatory variables to the gravitational model. Huo and Chen (2023) constructed

SFGM to verify the efficiency of service trade and found influencing factors based on the data of trade between China and the 27 EU member states from 2011 to 2020. They considered natural and human factors to analyze the trade potential in industries and countries. Zhang and Liu (2023) determined the influencing factors affecting the efficiency of China's digital service export using export data to RCEP member countries from 2006 to 2021 and found that the economic scale and population of RCEP member countries and their languages had significant effects, while the growth of the Chinese population and the borders between countries had a negative impact. Wang and Li (2023) constructed the SFGM of digital trade based on data from 2000 to 2020 to measure the efficiency and potential of China's digital trade with 27 major countries. The results showed that the efficiency of China's digital trade was low but the potential was huge, especially with Japan, South Korea, and Singapore. The trade potential of commercial services was the largest, followed by computer and information services, and the trade potential of communication services was the smallest.

Research on the trade potential of China's products with ASEAN countries has been concentrated on mechanical, electrical, and agricultural products. There has been little research on the trade of edible fungi. Zhang *et al*. (2019) used the panel data of cultural goods trade between China and ASEAN from 2002 to 2016 to establish an Extended Gravity Model with population size and common border to measure trade potential. Yan (2022) incorporated variables such as tariff level, infrastructure quality, political stability, government effectiveness, and free trade agreements (FTAs) into the trade inefficiency model and measured trade efficiency and potential by country and product. They found that China's exports of agricultural products to ASEAN had great potential. Based on the trade data from 2000 to 2020, Wang and Zhang (2022) measured the trade efficiency of China, the United States, Japan, South Korea, India, and ASEAN using SFGM and found that competitiveness was stronger than complementarity which was gradually increasing. The changes in the trade efficiency of trading partners showed strong convergence.

Trade potential has been researched mainly using gravitational models. Dadakas *et al*. (2020) used the Gravity Model and Poisson pseudo-maximum-likelihood (PPML) method to analyze and test the oil export data of the UAE from 2002 to 2016. The results showed that the UAE has lost its trade potential with most countries, but there were still opportunities to increase trade with countries such as Iran and Japan. Masood *et al*. (2023) studied the trade potential between Pakistan and South Asian countries using an Extended Gravity Model and showed that the imposition of tariffs and the GDP of partner countries positively impacted Pakistan's trade value with the common language, borders, and geographical distance. Xu *et al*. (2023) conducted an empirical study based on the relevant data of Vietnam's exports of agricultural products to APEC from 1998 to 2018 using SFGM. They found that trade barriers and technical readiness showed a positive correlation with agricultural exports, and Vietnam's export potential to China, the United States, Japan, and other national markets was huge.

With diverse research results on agricultural products or commodities, there are still few studies on the measurement of trade efficiency and specific agricultural products such as edible fungi. Most research on edible fungi was conducted on the characteristics and development of the cultivation technology, and a few attentions were paid to its trade. Research on edible fungi generally has been conducted in biology, food science, and engineering as technological competitiveness is important in the development of the edible fungi industry. China is the largest producer of edible fungi, and its trade is important for the sound development of the agricultural industry. Therefore, the study of the efficiency and trade potential of China's edible fungus is significant to increasing its exports, establishing trade policy, and optimizing the industrial structure. In most studies on trade efficiency and trade potential, SFGM has been used, and the "subjective trade resistance" has been included in the trade cost analysis to reduce the bias.

3. Model Construction

3.1. SFGM

In Tinbergen's (1962) traditional Gravity Model, the trade volume is directly proportional to the size of the two trading parties's economies and inversely proportional to the geographical distance between the two parties. However, in the traditional Trade Gravity Model, the subjective factors affecting trade are not considered though these factors play a non-negligible role in trade. This results in incorrect estimation. To include the factors and calculate the maximum potential of the trade, a Stochastic Frontier Model was proposed. The Stochastic Frontier Model (Meeusen and Broeck, 1977) decomposes the random interference into the random error and the trade inefficiency and includes the subjective factors that are not adopted by the traditional Gravitational Model to measure the trade potential accurately. The Stochastic Frontier Model is divided into time-varying and time-invariant models. The time-varying model is more widely used since the change of time is considered to be more accurate and in line with the actual situation.

SFGM is expressed as follows:

$$T_{ijt} = f\left(X_{ijt}, \beta\right) \exp\left(v_{ijt} - \mu_{ijt}\right), \mu_{ijt} \geq 0 \tag{1}$$

$$T^{*}_{ijt} = f(X_{ijt}, \beta)\exp(v_{ijt}) \quad (2)$$

$$TE_{ijt} = \frac{T_{ijt}}{T^{*}_{ijt}} = \exp(-\mu_{ijt}) \quad (3)$$

$$\mu_{ijt} = \{\exp[-\eta(t-T)]\}\mu_{ij} \quad (4)$$

$$\gamma = \frac{\sigma_{\mu}^{2}}{\sigma_{\mu}^{2}+\sigma_{\sigma}^{2}} \quad (5)$$

where T_{ijt} represents the actual trade value, T^{*}_{ijt} represents the potential trade value to be predicted, TE_{ijt} represents the trade efficiency of both trading parties, X_{ijt} represents different influencing factors, β represents the parameter vector, v_{ijt} and μ_{ijt} represent the random interference term and the trade non-efficiency term (v_{ijt} follows a normal distribution with a mean of zero, μ_{ijt} shows a semi-normal or truncated distribution, and both are independent of each other), and η is the parameter to be evaluated (When $\eta = 0$, the μ_{ijt} does not change with time, and is a time-invariant model. When $\eta \neq 0$, the μ_{ijt} changes with time, the model is time-varying). When the value of the γ is close to 1, the role of the non-efficiency term becomes important, and the stochastic frontier model must be used. Taking the natural logarithm of Eq. (1) leads to

$$\ln T_{ijt} = \ln f(X_{ijt}, \beta) + v_{ijt} - \mu_{ijt}, \mu_{ijt} \geq 0 \quad (6)$$

In SFGM, the influencing factors are classified into natural influencing and anthropogenic influencing factors. Natural factors occur naturally and cannot be artificially changed in a short period of time, such as Gross Domestic Product (GDP), total population, geographical distance, and common borders. Anthropogenic factors are susceptible to human intervention such as trade freedom, government effectiveness, political stability, air cargo volume, official exchange rates, and trade openness. Table 2 presents the influencing factors selected in the SFGM of this research.

Table 2. Influencing factors of SFGM in this research.

Factors	Explanation
Natural Influencing Factors	
GDP	A country's Gross Domestic Product (GDP) represents the country's production status and economic development level and impacts the scale of trade between the two trading parties. In general, countries with better economic capacity pay more attention to foreign trade, and the volume of import and export trade tends to be higher.
Population	The larger the population of the exporting country, the richer the labor resources, and the lower the production cost, thereby increasing the supply capacity and promoting exports. The larger the population of the importing country, the greater the domestic demand, the replacement of some domestic output for imports, and the relative reduction of trade activity.
Geographical Distance	Geographical distance usually refers to the distance between the capitals of two countries. Generally speaking, geographical distance affects the cost of logistics and transportation and thus affects bilateral trade. The longer the distance, the greater the cost, and the cost is lowered.
Common Border	If two countries that trade are close to each other (there is a common border), not only will the logistics and transportation be convenient (low cost and high efficiency) but also the cultural proximity may lead to harmonious trade relations and increase the volume of bilateral trade. Generally speaking, a common boundary is a dummy variable, and if it exists, it is assigned a 1, and if it does not exist, it is assigned a 0.
Anthropogenic Influencing Factors	
Degree of Trade Freedom	The degree of trade freedom is used to measure the trade-weighted average tariff rate and the number of non-tariff barriers in a 100-point system to score countries. Generally speaking, countries with a high degree of trade freedom have relatively lower tariffs than conducting bilateral trade.
Government Effectiveness	Government effectiveness is a comprehensive governance factor consisting of a country's political status, the effectiveness of policies, and the efficiency of the government. The high efficiency of implementation by the governments of importing countries alleviates the non-trade efficiency in the process of exporting to them to a certain extent, thereby improving the efficiency of their export trade and fully releasing their export trade potential.

Political Stability	Perceptions of the likelihood of political instability and politically motivated violence are used to measure in terms of the absence of violence or terrorism, and thus the overall score of each country is calculated, usually about -2.5 to 2.5. Politically stable countries have a better trade environment generally increasing trade activity. Conversely, politically volatile countries are often detrimental to trade efficiency.
Air Cargo Volume	Air cargo volume refers to the number of passengers, luggage, mail and cargo carried by air transport enterprises using aircraft within a certain period, reflecting the volume of transportation and production of air transport enterprises. Generally speaking, a higher volume of air cargo indicates more frequent trade.
Official Exchange Rate	The official exchange rate is the annual average (the value of the unit of the local currency relative to the United States dollar) calculated on the basis of the monthly average, either by the national authorities or by the legal foreign exchange market. Generally speaking, the increase in the exchange rate of the country and the appreciation of the local currency are conducive to imports.
Trade Openness	Trade openness is expressed as the ratio of a country's total imports and exports to the country's GDP to measure the degree of market openness of a country. The more open the market, the fewer trade barriers, and the trade flow between the two sides increases. Since edible fungus products are traded in tangible ways, trade openness is calculated as the proportion of a country's merchandise trade volume in the country's GDP.

Based on the availability of explanatory variables, the data of China and ASEAN countries (except Laos) from 2003 to 2022 were collected to estimate the export volume of Chinese edible fungus products to ASEAN in this research. In the SFGM of this research, natural factors such as economic scale and population were included, while the subjective influencing factors were used to estimate the trade inefficiency and trade potential. The SFGM (master model) and the Trade Inefficiency Model (sub-model) were established as follows.

$$\ln EX_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln POP_{it} + \beta_3 \ln GDP_{jt} + \beta_4 \ln POP_{jt} + \beta_5 \ln DIST_{ij} + \beta_6 BOR + \nu_{ijt} - \mu_{ijt} \quad (7)$$

$$\mu_{ijt} = \alpha_0 + \alpha_1 TF_{jt} + \alpha_2 GOVE_{jt} + \alpha_3 POLS_{jt} + \alpha_4 \ln AIR_{jt} + \alpha_5 \ln PA_{jt} + \alpha_6 OPEN_{jt} + \varepsilon_{ijt} \quad (8)$$

Table 3 shows the description of the variables of the models and the relationships between the variables. The data of Laos was not included in the model. To reduce the heteroskedasticity and autocorrelation of the model, EX_{ijt}, GDP_{it}, POP_{it}, GDP_{jt}, POP_{jt}, $DIST_{ij}$, AIR_{jt}, and PA_{jt} were logarithmically processed. The trade inefficiency model included the resistance factors that have negative relationships with trade volume.

Table 3. Descriptions of data and Meaning of variables of models in this research.

Type of Variables	Type of Models	Name of Variables	Meaning	Expected Sign	Data Sources
Dependent variable		EX_{ijt}	China's export trade volume of edible fungus products to ASEAN		UN Comtrade
Independent variables	SFGM (master model)	GDP_{it}	China's GDP	+	WDI
		POP_{it}	China's population	+	WDI
		GDP_{jt}	GDP of ASEAN countries	+	WDI
		POP_{jt}	Population of ASEAN countries	+	WDI
		$DIST_{ij}$	Geographical distance between China and ASEAN countries	-	CEPII
		BOR	Common border	+	CEPII
	Trade Inefficiency Model (sub-model)	TF_{jt}	Degree of trade freedom	+/-	The Heritage Foundation (Index of Economic Freedom)
		$GOVE_{jt}$	Government effectiveness	+/-	WGI
		$POLS_{jt}$	Political stability	+/-	WGI
		AIR_{jt}	Air cargo volume	+/-	WDI
		PA_{jt}	Official exchange rate	+/-	WDI
		$OPEN_{jt}$	Trade openness	+/-	WDI

The efficiency of the models was calculated using the "one-step method" and "two-step method". As the two-step method ignores the influencing factors of technical efficiency, the results are prone to bias. Therefore, the "one-step method" model was selected in this research (Eq. (9)).

$$\ln EX_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln POP_{it} + \beta_3 \ln GDP_{jt} + \beta_4 \ln POP_{jt} + \beta_5 \ln DIST_{ij} + \beta_6 BOR + \nu_{ijt}$$
$$-(\alpha_0 + \alpha_1 TF_{jt} + \alpha_2 GOVE_{jt} + \alpha_3 POLS_{jt} + \alpha_4 \ln AIR_{jt} + \alpha_5 \ln PA_{jt} + \alpha_6 OPEN_{jt} + \varepsilon_{ijt}) \quad (9)$$

3.2. China's Export of Edible Fungus Products to ASEAN

For China, ASEAN is an important trade partner. According to the General Administration of Customs of China, in the first 11 months of 2023, ASEAN was China's largest trading partner with a total value of USD 0.81 trillion, accounting for 15.3% of China's total exports with a year-on-year increase of 0.1%. China's agricultural exports reached USD 87.34 billion showing an increase of 6.6%. China's export of edible fungus products to ASEAN was decreased till 2022 (Fig. 1).

From the perspective of export trade volume, China's exports to ASEAN increased significantly before 2018. In 2003, the export value was USD 55 million, and in 2018, it reached USD 2.265 billion, increasing by 40 times. The increase to USD 311 million in 2010 was enabled by the China-ASEAN FTA with zero tariffs and the abolition of restrictions. The increase to USD 753 million in 2013 was contributed to the initiative of "jointly building a closer China-ASEAN community, which encouraged enterprises to penetrate the global market. However, since 2019, due to the overall decrease in demand and the impact of technical trade barriers in various countries, China's exports declined, falling to USD 1.93 billion. Since then, due to the impact of COVID-19, China's exports decreased, indicating that the ASEAN market has shown challenges to China with a lot of room for improvement.

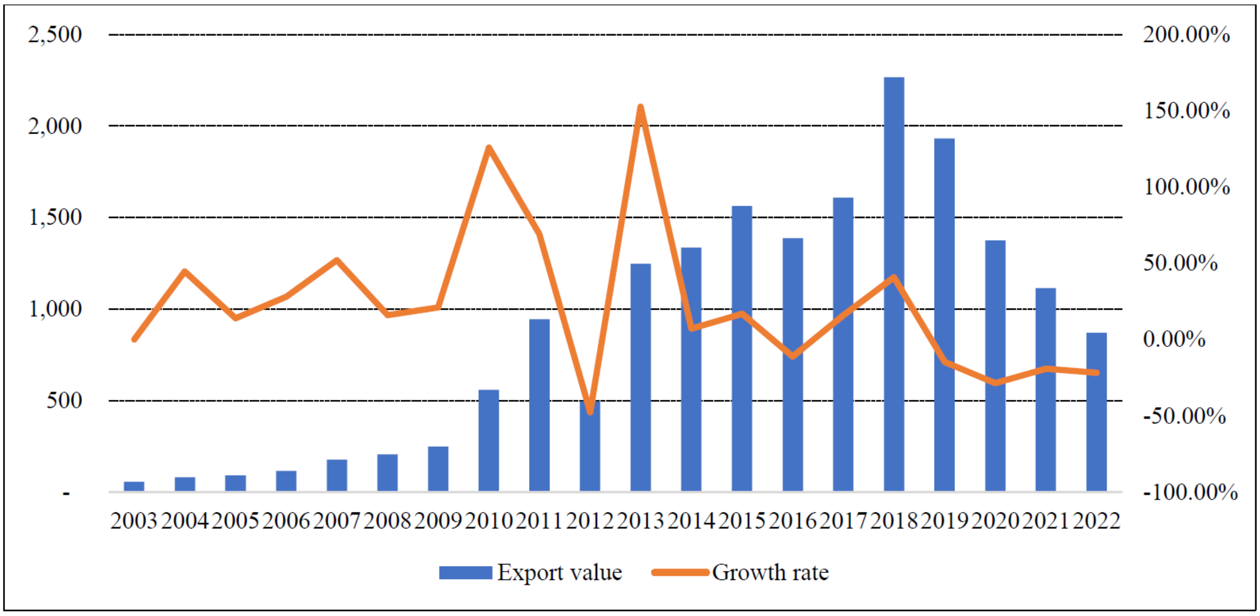

Fig. 1. China's export value and growth rate of edible fungus products to ASEAN from 2003 to 2022 (US million on *y*-axis). (UN Comtrade Database; the export growth rate was calculated based on 2003).

In the growth rate of exports, the annual fluctuation was observed. Thanks to the increasing trade between China and ASEAN, the growth rate in 2010 and 2013 was as high as 125.76 and 152.56%. However, in the past four years, the growth rate of trade has decreased but the total value has increased. Especially in 2020, due to the impact of COVID-19, global demand declined and the trade growth rate was -28.75%. With the stabilization of the epidemic, the global demand for edible fungi has rebounded and the export growth rate has been picking up, indicating potential for the ASEAN market. The product structure of China's edible fungus products has become different. In the past 20 years, the export of "dry edible fungus products" has been increasing, accounting for 75.39% of the total exported products. "Canned" edible fungus products accounted for 17.82%. The export of "fresh and refrigerated" edible fungus products was still limited with the proportions of 6.51%. Due to the restrictions of logistics and transportation, the export of fresh products is difficult and needs improvement. "Salted products for preservation" was the least exported only with a proportion of 0.27% (Fig. 2). Certain product types were preferred by ASEAN, indicating a weak risk hedge and an unstable product structure.

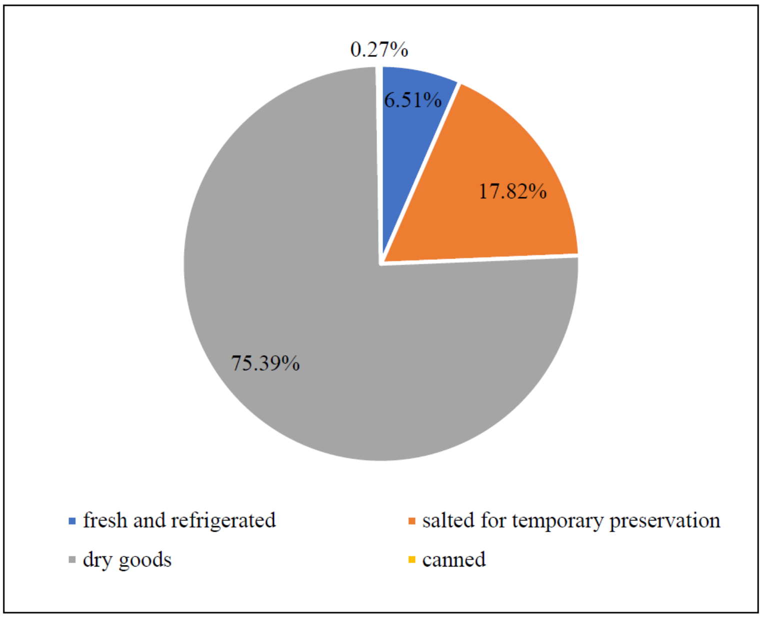

Fig. 2. Types of products of China's edible fungus exported to ASEAN from 2003 to 2022. (UN Comtrade Database).

As shown in Fig. 3, China's exports of edible fungus products to ASEAN were concentrated in Vietnam, Thailand, and Malaysia, accounting for 89.29%. The export volume to Vietnam accounted for 48.29%, which showed high dependence and might cause long-term imbalanced trade. Southeast Asian countries are adjacent to China and have similar dietary customs, so there is a greater demand for Chinese edible fungi. The total import volume of a country is related to the degree of national economic development. Economically developed countries have large consumption potential, so their demand for edible fungus products is expected to grow, while economically underdeveloped countries such as Myanmar, Cambodia, Laos and Brunei Darussalam have smaller market sizes and less demands.

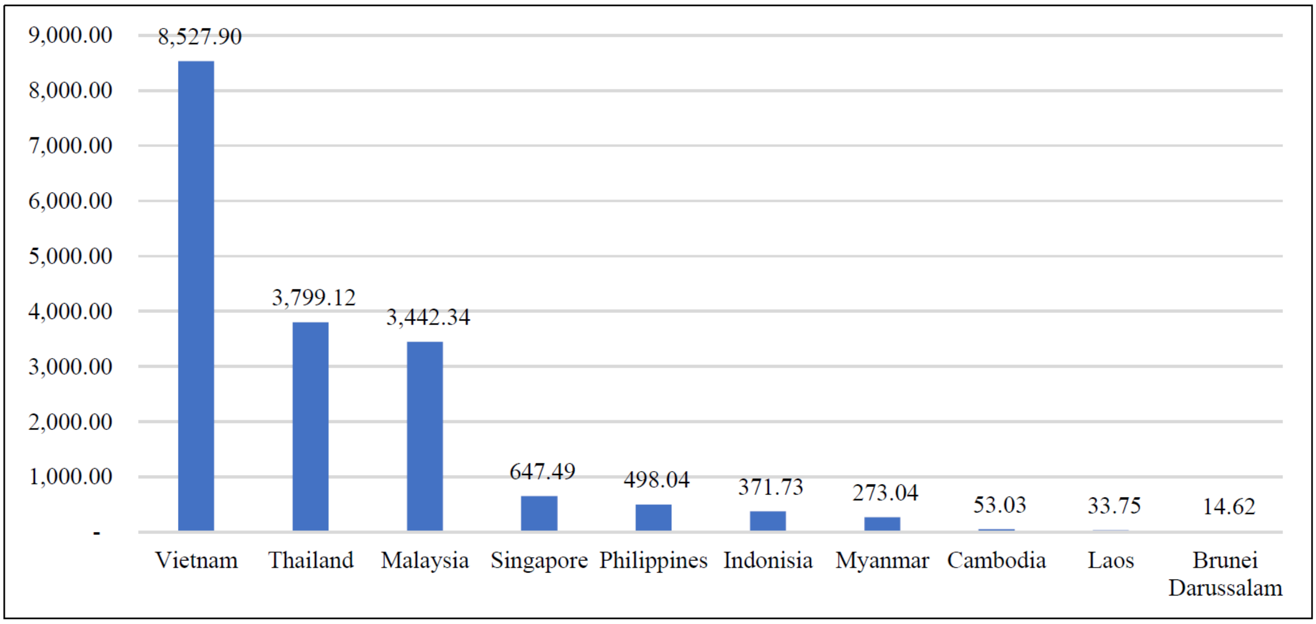

Fig. 3. China's total export of edible fungus products to ASEAN countries from 2003 to 2022. (USD million on *y*-axis, UN Comtrade Database).

4. Analysis of Trade Potential

4.1. Fitness Test of Model

To obtain accurate results of SFGM, the applicability was tested using the maximum likelihood ratio test. The variables of the model were tested to see their impacts on the export of edible fungus products. The existence of trade inefficiency was tested, and the time-varying nature of trade inefficiency was examined. To determine the influence of $\ln DIST_{ij}$, *BOR* was used. Null hypotheses were proposed as shown in Table 4. The likelihood ratio test was used with the log-likelihood values of constrained and unconstrained cases and was compared with the value of the mixed χ^2 distribution at the significance level of 1%. The hypothesis that trade inefficiency did not exist was rejected at the significance level of 1%. As there was trade inefficiency in the export of China's edible fungus products to ASEAN, the Stochastic Frontier Model was not used. At the same time, the null hypothesis that trade inefficiency did not change over time was also rejected. Thus, the time-varying factor was included in the analysis. The hypotheses that geographic distance or common boundary variables did not influence the export were rejected, suggesting the inclusion of these two variables.

Table 4. Tests for SFGM.

Null hypothesis	Likelihood values of constrained model	Likelihood values of unconstrained model	*LR*-Statistics	Value at the significance level of 1%	Result
There is no trade inefficiency.	-312.612	-285.583	54.058	8.273	Rejected
Non-efficiency items do not change over time	-285.583	-276.079	19.008	10.501	Rejected
Geographic distance does not influence the export.	-285.590	-276.079	19.022	5.412	Rejected
Common boundary does not influence the export.	-285.068	-276.079	17.978	5.412	Rejected

4.2. Results of SFGM

The time-varying SFGM was constructed based on the test results. Frontier 4.1 software was used to conduct a regression analysis of China's exports from 2003 to 2022. The regression results for time-varying and unvaring models were tested as shown in Table 5.

The log-likelihood values and LR test values of each variable of the time-varying and unvarying models were similar, which indicated the robustness of the SFGM in this research. In the time-varying model, the γ value was 0.911 at the significance level of 1%, indicating that there was trade inefficiency in China's exports, and the proportion of trade inefficiency in the difference between the actual trade and potential values of exports was large. The LR test results showed the necessity of further analysis of the influencing factors of trade inefficiency. The η value of the trade inefficiency coefficient was -0.04, indicating decreased trade efficiency and its changes with time. Thus, the time-varying model was more appropriate than the time-unvarying model. The variable coefficients and t values implied that the regression coefficients of China's ln*GDP* and the ln*GDP* of the importing countries were positive (consistent with expectations). Thus, the GDP of China and the importing countries promoted the trade potential of China's exports owing to China's economic development and the increased supply capacity. The economic growth of importing countries has increased the general income level and the demand for edible fungus products, increasing the export. However, China's ln*GDP* was not significant because the GDP of China did not significantly impact its exports compared to the GDP of importing countries. The regression coefficient of ln*GDP* of importing countries (1.483) was higher than that of China's ln*GDP* (0.355), indicating that the ability to import had a more significant effect on the export of China than the supply capacity.

The regression coefficient of ln*POP* of the total Chinese population was significant at 5%. For an increase in population of 1%, the exports increased by 30.77%. This indicated that China's population contributed to the potential of China's exports. China's population generates domestic market demand, and the increased domestic production increases China's export supply. The regression coefficient of ln*POP* of the total population of the importing country was negative. The population of the importing country inhibited the export potential of China. In addition, the increase in population of the importing country did not necessarily mean the expansion of the domestic market demand. The increase in population limited the increase of per capita income and consumption capacity of the importing country. It also limited import capacity, inhibiting the exports of Chinese. The insignificant regression coefficient was contributed to by random errors in the data. The regression coefficient of ln*DIST* was negative, indicating that geographical distance hindered the exports due to increased transportation costs. The regression coefficient of BOR was negative. In general, the closer countries, the less cost for logistics, and the less cultural differences, which provides advantages in trading.

Table 5. Regression results of SFGM.

Estimation method	**OLS model**		**Time-invariant model**		**Time-varying model**	
variables	coefficient	t-value	coefficient	t-value	coefficient	t-value
CONS	109.579	0.343	59.294	0.236	-627.029**	-2.432
lnGDP_{it}	0.521	0.776	0.162	0.283	0.335	0.674
lnPOP_{it}	-5.394	-0.335	-2.433	-0.191	30.766**	2.403
lnGDP_{jt}	1.697***	14.362	2.101***	7.924	1.483***	6.512
lnPOP_{jt}	-0.355***	-3.931	-0.624**	-2.426	-0.196	-1.088
ln$DIST_{ij}$	-3.941***	-6.712	-4.585**	-2.549	-5.242***	-4.221
BOR	-0.306	-0.928	-0.885	-0.086	-5.303***	-4.315
σ^2	1.965		2.164***	3.115	10.928***	3.799
γ	-		0.433**	2.352	0.911***	38.449
η	-		-		-0.040***	-5.068
Log-likelihood value	-312.612		-285.583		-276.079	
LR test value	-		54.059		73.067	

Source: Compiled from Frontier 4.1 results.

Note: *, **, and *** represent significant levels of 10%, 5%, and 1%, respectively.

4.3. Trade Inefficiency

The SFGM was integrated into the trade inefficiency model to obtain the export efficiency of edible fungus products and measure the trade potential and expandable potential of China. The "one-step method" of the BC95 model was used to avoid the endogenous contradiction of the "two-step method". In model regression, total exports, four natural factors (lnGDP_{it} and lnGDP_{jt}, population lnPOP_{it} and lnPOP_{jt}, geographical distance ln$DIST_{ij}$, common border *BOR*), and six anthropogenic factors (degree of trade freedom TF_{jt}, government effectiveness $GOVE_{jt}$, political stability $POLS_{jt}$, air cargo volume lnAIR_{jt}, official exchange rate lnPA_{jt}, trade openness ($OPEN_{jt}$) were included for estimation. 240 observations were processed for regression, and the results are shown in Table 6.

Table 6. Trade Inefficiencies Model results.

SFGM			**Trade Inefficiencies Model**		
Variables	Coefficient	t-value	Variables	Coefficient	t-value
CONS	6.234	0.040	*CONS*	57.155***	5.963
lnGDP_{it}	0.859***	3.264	TF_{jt}	-8.765***	-4.475
lnPOP_{it}	-2.675	-0.347	$GOVE_{jt}$	-2.058**	-2.578
lnGDP_{jt}	0.451***	5.683	$POLS_{jt}$	0.877**	1.988
lnPOP_{jt}	0.790***	12.839	lnAIR_{jt}	-0.208	-1.268
ln$DIST_{ij}$	2.161***	5.290	lnPA_{jt}	0.070	0.911
BOR	1.943***	7.940	$OPEN_{jt}$	-4.055***	-6.290
Log-likelihood value	-228.408		σ^2	3.264***	5.933
LR test value	168.408		γ	0.993***	130.027

Source: Compiled from Frontier 4.1 results.

Note: *, **, and *** represent significant levels of 10%, 5%, and 1%, respectively.

The variables in the model passed the significance test with σ^2 and γ, indicating that they had enough explanatory power for the export value. At the same time, variables in the models showed consistent significance, indicating robust regression results. The

γ value in the regression results was close to 1, indicating that the trade inefficiency played an important role. The γ value was 0.993, so trade inefficiency deteriorated exports by 99.3%. The regression results showed that trade inefficiency was important for trade resistance, and four of the six anthropogenic influencing factors significantly impacted it. TF_{jt} was negative at the significance level of 1%, indicating that trade freedom impacted trade inefficiency. The impact value of the coefficient was -8.765, indicating that for every 1% increase in the trade freedom of ASEAN countries, the trade inefficiency of China decreased by 8.765%. At the significance level of 5%, the government efficiency $GOVE_{jt}$ passed the significance test, indicating that the government efficiency had a significant impact on the export trade inefficiency of edible fungus products, and had a negative impact on the trade inefficiency, which was in line with expectations. The absolute value of the coefficient of government efficiency is 2.058, indicating that government efficiency has a great impact on the non-efficiency item of trade. Specifically, when the government efficiency index of the importing country rises by 1 unit, the non-efficiency value of edible fungus products exported by China to the country in trade will be reduced by 2.06% accordingly. This data fully proves that the government efficiency of the importing country has a significant role in promoting the export trade of edible fungus products in China. Political stability $POLS_{jt}$ is significant at the level of 5%, but the sign is positive, which is not in line with expectations, perhaps because the politics of ASEAN countries have been relatively stable, resulting in its promotion of China's edible fungus product exports is not obvious. The air cargo volume $\ln AIR_{jt}$ and the official exchange rate $\ln PA_{jt}$ failed to pass the significance test, which showed that despite the large air transport volume and high official exchange rate, the promotion effect on the export of edible fungus products in China was not significant because the export transportation mode of edible fungus products was not necessarily shipping, and the exchange rate fluctuation factors were more complex, which could not have a significant impact on the export trade of edible fungi. In addition, the sign of the official exchange rate is positive, which is not as expected, perhaps due to differences in data processing. However, the value is relatively small and accounts for a small proportion of the non-efficiency item of trade. At the significance level of 1%, the trade openness $\ln OPEN_{jt}$ passed the significance test, and its sign was consistent with expectations, which fully indicated that the trade openness had a significant impact on the non-efficiency item of edible fungus products. The absolute value of the coefficient is 4.055, which means that for every 1% increase in the trade openness of ASEAN countries, the non-efficiency value of China's export trade of edible mushroom products to the country will only decrease by 4.06%. The higher the degree of openness, the reduction of trade barriers, and the increase of trade volume, which also shows that the trade openness of various countries can promote the increase of China's edible fungus product export trade volume to a small extent.

4.4. Trade Efficiency

From 2003 to 2022, the average trade efficiency of China's edible fungus products exported to ASEAN was 0.369, indicating untapped potential. The trend was measured in terms of trade efficiency using annual and national averages (Fig. 4 and Fig. 5). The trade efficiency of China's exports was stable in the annual average between 0.2 and 0.6 with a slight decrease. This means that over the past two decades, although China's export efficiency in this area has remained relatively constant, it still faces a number of challenges. In particular, trade efficiency has rebounded rapidly after a significant decline in 2012, but since the outbreak of the coronavirus pandemic in 2020, trade barriers have surged and led to a sharp decline in efficiency.

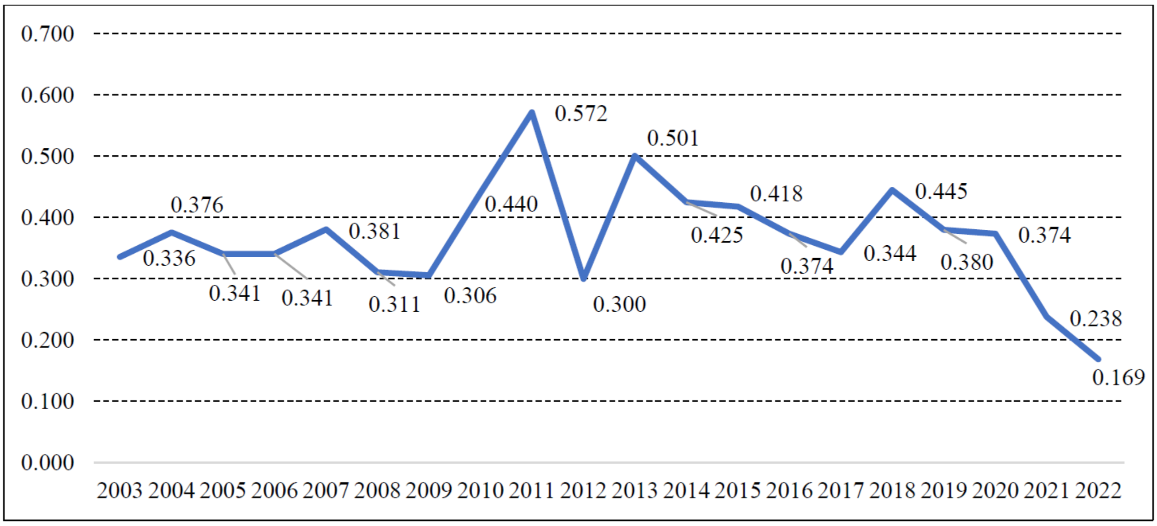

Fig. 4. Annual trade efficiency of China's exports of edible fungus products to ASEAN countries from 2003 to 2022.

In general, the trade potential of edible mushroom products has not been fully tapped, and in recent years, it has encountered significant development problems, and the growth of export trade is still largely affected by non-efficiency factors. However, this situation also indicates that after overcoming these challenges, there will be new development opportunities in the relevant trade sector.

From the perspective of country averages, the trade efficiency of China's exports of edible mushroom products to ASEAN varies greatly. Malaysia and Singapore have values around 0.7, while Myanmar and Indonesia have only 0.016 and 0.008 values. It can be seen that the extreme gap is large, and nearly half of the countries are below the average value of 0.368, indicating that the ASEAN market still has a lot of potential to tap into the space. In general, the average trade efficiency of edible mushroom products exported by China to ASEAN countries is widely distributed, and the level varies greatly.

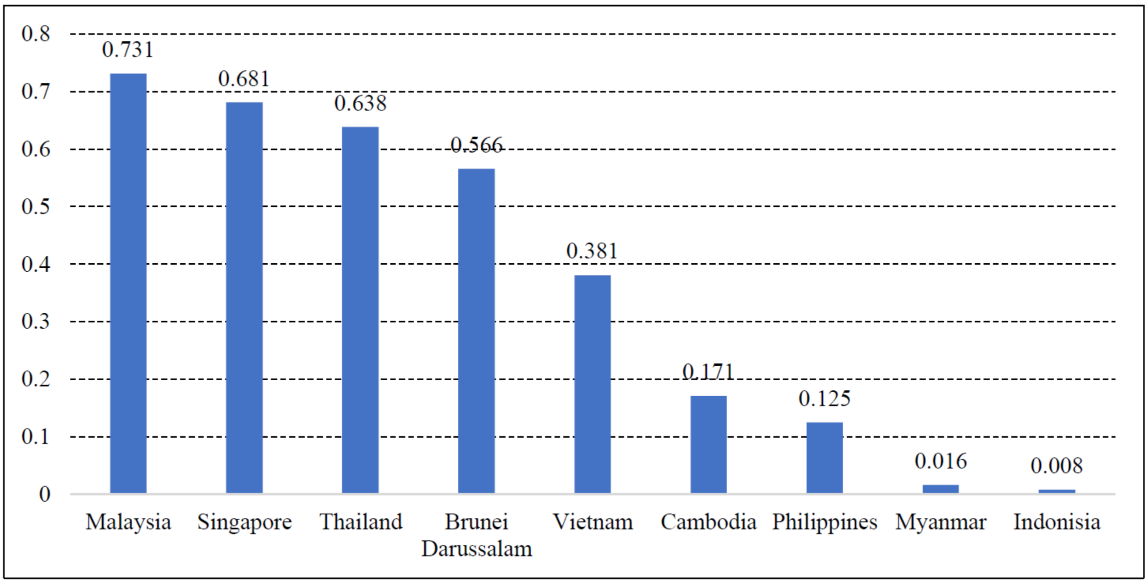

Fig. 5. Trade efficiency by country of China's exports of edible fungus products to ASEAN countries from 2003 to 2022.

4.5. Trade Potential and Its Improvement

Equations (10) and (11) were used to calculate the trade potential and the potential for improvement of China's edible fungus products exported to ASEAN countries from 2003 to 2022.

$$TP = ATV/TE \quad (10)$$

$$TPIS = TP - ATV \quad (11)$$

where *TP* represents the trade potential value, *ATV* represents the actual export value, *TE* represents the trade efficiency value, and *TPIS* represents the potential for improvement.

Since the trade potential represents the optimal size of the trade, a higher trade potential does not necessarily mean an increase in trade. However, the comparison of the trade potential with the actual trade volume is an important reference to understanding the increase in China's exports. Fig. 6 shows that China's country-specific trade potential varied greatly. The AESAN countries were grouped with great potential, potential development, and potential reconstruction with a criterion of USD 200 and 400 million. Indonesia, Vietnam, and Myanmar belonged to the group with great potential. China's trade potential with Indonesia was the largest with USD 2.834 billion, and it is the only country among ASEAN countries with a value of more than 1 billion US dollars. China's trade potential with other countries was much lower than with Indonesia, implying that they have untapped trade potential and China must develop the markets. Thailand, the Philippines, and Malaysia belonged to the group with potential development. The average trade potential was between USD 200 to 400 million. The economies of these countries are being rapidly developed. Although there is a gap between countries, there is a large room for growth. China needs to turn export possibilities into actual exports. The third group included Singapore, Cambodia, and Brunei, with potential reconstruction. The average trade potential of these countries was below USD 200 million. The trade potential of Cambodia and Brunei was the lowest with values of USD 20.34 and 1.44 million. The countries' economic situations restricted China's exports. Even if the trade resistance is reduced, China's exports may be difficult. Singapore's low trade potential was explained by the fact that China's trade was high enough so the trade potential was low.

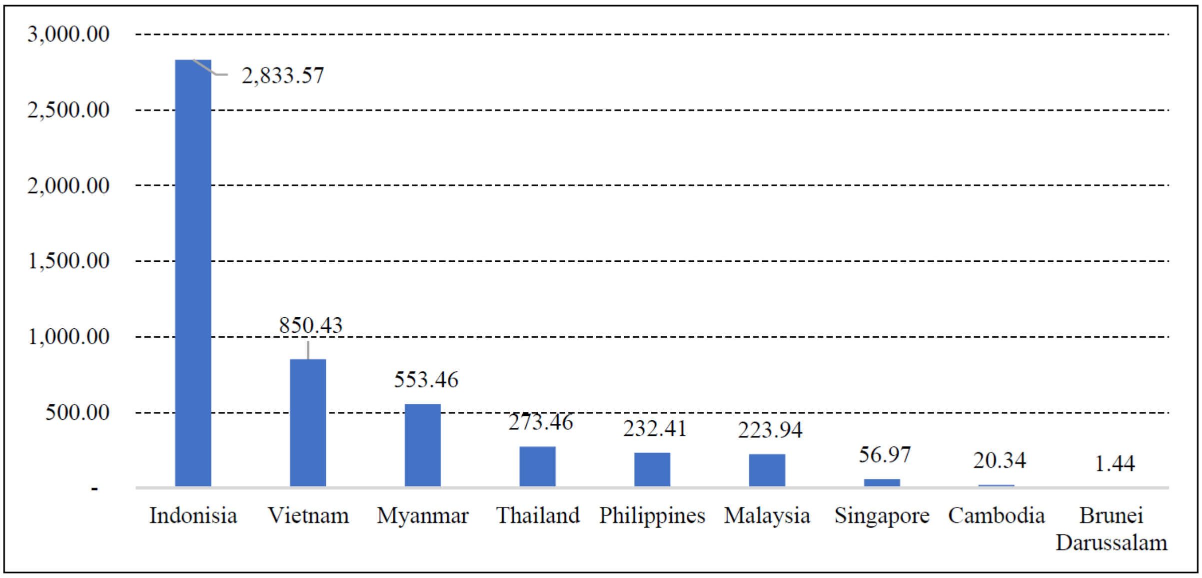

Fig. 6. Trade potential of China to ASEAN countries from 2003 to 2022 (USD million on *y*-axis).

The difference in the potential of China's exports to ASEAN countries was explored by calculating the trade potential of each country (Fig. 7). A large difference was observed in the trade potential, and the ranking of the trade potential was similar to the actual trade value. Cambodia, Singapore, and Brunei had less room for improvement in trade potential. Cambodia and Brunei showed the lowest prospects which need to be continuously improved. As Singapore already has exported considerably, so the present status needs to be maintained. Indonesia, Myanmar, and Vietnam deserve the exploration of new trade possibilities. The results suggested that the export volume of edible fungi needs to be increased to Indonesia, and the present levels need to be maintained for Myanmar and Vietnam.

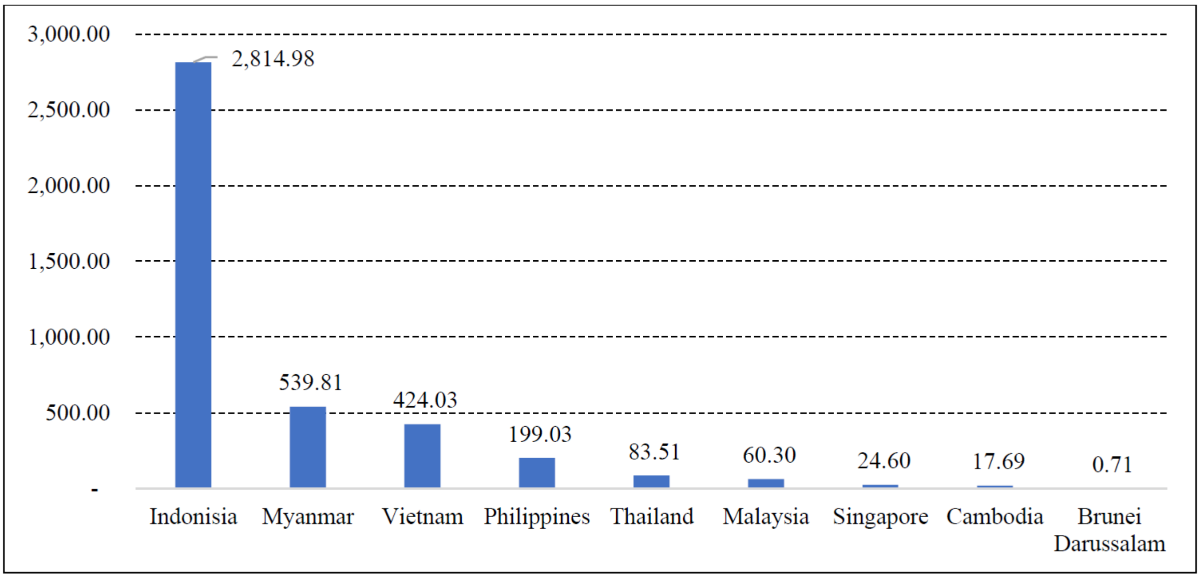

Fig. 7. From 2003 to 2022, China's exports of edible mushroom products to ASEAN countries can be improved by the average trade potential of each (USD million on *y*-axis).

5. Conclusions

Based on the data from 9 ASEAN countries from 2003 to 2022, factors and their impacts on the export of edible fungus products from China were investigated. The trade potential was studied by estimating the potential of trade. From 2003 to 2020, the e scale of China's exports of edible fungus products to ASEAN was enlarged but has decreased in the past three years due to simple product types, uneven distribution, and excessive concentration of domestic markets. These problems have influenced the long-term balanced development of China's exports. Trade inefficiency was observed in the exports of edible fungus products with changes with time. Using SFGM, the time-varying and unvarying factors were determined. The results of this research showed that the GDP, total population, and common borders between China and importing countries affected the trade potential. The degree of trade freedom and government effectiveness also influenced the trade potential, while the government effectiveness caused the trade inefficiency largely. The trade potential and the potential for improvement were evaluated. The trade potential of Indonesia, Vietnam, Myanmar, and the Philippines was higher, and that of Thailand and Malaysia was in the middle. Singapore, Cambodia, and Brunei had the lowest potential for different causes. Based on the research results, the following suggestions were made.

The product structure of edible fungus products needs to be diversified as dry products have been mainly exported with a high dependence, and value-added products are rare. There are barriers to the R&D of edible fungus products in China, and the competitiveness in scientific and technological innovation and production is weak. This leads to labor-intensive manufacturing. Therefore, the overall quality of China's edible fungus products is inferior compared with that of developed countries. Therefore, China must invest in high-tech R&D with government subsidies to develop processing technology and add value to edible fungus products. At the same time, competitiveness in the global market must be secured with targeted product development and promotion by branding products. The industry must increase the supply and continuously optimize the export structure for the sustainable and healthy development of China's agricultural economy.

Indonesia, Vietnam, Myanmar, and the Philippines were found to have large trade potential and improvement. Therefore, the exports to these countries must be increased by exploring the markets and establishing appropriate trade directions and foundations. Thailand and Malaysia also have large potential so investigation and research of the markets are required. Exports to Singapore must be maintained while Cambodia and Brunei need differentiated marketing strategies. At the same time, China must coincide with the global standard of the edible fungus industry and enhance its ability to overcome technical barriers.

The government effectiveness of the importing country impacted the exports significantly. Thus, China must communicate and contact ASEAN governments with appropriate services and cooperation with ASEAN countries and introduce favorable policies and simplified bilateral trade protocols. In addition, the advantage of the "Belt and Road" initiative must be integrated and advertised in various countries to enable countries to make decisions for favorable trade. This also helps companies cooperate in the edible fungus industry.

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