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Research Article

Assessing the Efficiency and Potential of China's Apple Exports

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This study elucidates the factors impacting China's apple trade, its efficiency, and opportunities for increased revenue. This study adopts a stochastic frontier gravity model on China's apple exports data, covering the period from 1997 to 2022 across 38 significant trading partners. The finding demonstrates that the economic growth of China and its trading partners substantially boosts apple export volumes, with a positive correlation between GDP growth and export flows. The research also highlights the deterrent effect of geographical distance on exports and reveals a complex negative relationship between the per capita GDP of importing nations and export efficiency, shedding light on the nuanced nature of trade dynamics. Furthermore, the study finds that the appreciation of China's currency plays a crucial role in enhancing export efficiency by lowering transaction costs. Meanwhile, increased agricultural land in importing countries presents competitive challenges, impacting export performance negatively. Geographical proximity and infrastructural features, such as shared borders and lack of access to seaport, are identified as significant factors in export efficiency. The analysis unveils considerable untapped export potential in various countries, suggesting a strategic avenue for market expansion. To optimize China's apple export strategy, policymakers are advised to consider currency management, negotiate trade agreements that mitigate distance and per capita GDP effects, and target markets with high untapped potential, thereby facilitating sustainable growth in China's apple export sector.

1. Introduction

It is widely recognized that exports are an essential channel for a country's agricultural products to enter the international market and to digest domestic agricultural production capacity, which is also conducive to the economic growth of exporting countries [1–3]. In terms of fruit products, an estimated 80% of all fruits grown globally are sold as whole fresh fruits. The export of most international fresh fruits is growing, with an annual growth rate of nearly 7% in the last decade. China is the world's largest producer of apples and the country has also rapidly expanded its exports of fresh and processed apples [4]. Significantly, the growing demand for fresh produce in emerging and developing economies worldwide has driven significant growth in the fresh apple market [5]. Similarly, the global apple market is growing due to the rising popularity of fresh apples for their health benefits, the advancement of new hybrid varieties, and the increase in contract farming, among other factors [6]. Emerging markets, such as China, are playing a significant role in the global fruits' market. The fact that the export share of apples was second only to bananas in 2018, apple exports have been one of the most dynamic activities of the international fruits trade in recent years [7]. At the same time, apple is the second-largest garden fruit in China, its export trade status is of great significance in enhancing the level of China's agricultural products in the international market [8].

According to the statistics of the Food and Agriculture Organization of the United Nations (FAO), there were about 93 countries and regions in the world that produced apples in 2022. The apple market can be segmented based on geographical location into North America, Europe, Asia-Pacific, South America, and the Middle East & Africa [9].

Due to a long production history and ideal climatic and geographical conditions [10], China's apple production area and output have continued to be ranked first in the World and the Asian Pacific region since 1988 and 1992, respectively. In 2022, China's area under apple production and output were 2.13 million hectares and 4.76 million tons, accounting for 44.10% and 49.63% of the world's total. In addition, China has dominated the global apple industry in terms of its production and consumption capacities. Despite the country's large population and the presence of a significant market for apples, the export of apples is also significant on a global scale. For instance, China's share of the global apple export market reached its peak at 20% in 2016, before dropping to 17% in 2019 and further declining to 15.6% in 2022. Although this proportion seems small when compared with the production capacity of China, from 1997 to 2022, the export volume of apples continued to increase until the financial crisis of 2008 when global apple market demand was sluggish [11], and the export volume of China's apples began to decline. Although it increased in the subsequent year, it could not eliminate the negative impact of the international market (Figure 1). Moreover, it is foreseeable that, with the limitation of domestic apple consumption capacity in the long run, apple exports will gradually become a meaningful way to digest apple production capacity in China. Meanwhile, changes in China's apple production and trade conditions can alter the pattern of global apple production and trade patterns.

Studies on China's agricultural trade have mostly focused on various sectors and subsectors. For example, Suroso et al. [12] examined the factors influencing and the potential impact of China's tea exports on economic growth in China. The authors applied the gravity model and the Autoregression Distributed Lag (ARDL) model to a dataset covering the years 2010 to 2020. The study identified certain factors as the main drivers of tea exports and found a positive and significant relationship between tea trade and economic growth, both in the long and short term. Abdullahi et al. [13] investigated the factors that influence China's agricultural exports by employing the fixed effect and Poisson Pseudo Maximum Likelihood (PPML) frameworks. Their study revealed a strong correlation between China's export flows and variables such as GDP, the Chinese language, shared border, and the belt and road initiative (hereafter BRI). Dang and Pang [14] used input-output table data from the years 2002, 2007, 2010, and 2015 in order to construct a computable general equilibrium model of global trade. The purpose of this model was to evaluate the influence of bilateral agricultural product trade between China and the Belt and Road (B&R) countries, which is commonly known as the border effect. They showed that the border effect of agricultural product trade decreased by 20.9% in 2015 compared to 2010. This suggests that the Belt and Road (B&R) initiative has, to some degree, decreased trade barriers and facilitated bilateral agricultural trade between China and B&R countries.

Nasrullah et al. [15] presented a case study that examined China's exports of forest products to the global market using the conventional gravity model. The study revealed that both GDP and GDP per capita have a positive influence on Chinese exports, while distance has a negative impact. Furthermore, the study suggested that promoting the Chinese language to importing countries could enhance export relations with China's partners. Sun and Li [16] focused on the trade margins of China's agricultural exports to the Association of Southeast Asian Nations (ASEAN) by utilizing the 2000–2015 data. The results suggest that the key driver of growth for Chinese agricultural exports to ASEAN has undergone a shift from the extensive margin, particularly prior to the establishment of the China-ASEAN Free Trade Area (CAFTA).

Despite China's prominent position in the global apple industry, little is known about the factors that influence its apple trade, the efficiency of its trade operations, and whether there is potential for China to increase its revenue from apple trade. In recent decades, China's government and fruit processing industries have directed significant attention towards the apple industry, motivating our work. In addition, export is regarded as the main drive of economic growth and an important component of China's economy. Thus, the apple industry emerges as a significant focal point for China's rural revitalization efforts. This study aims to offer valuable insights into the government's strategies for supporting apple farmers by enhancing both apple production and farmers' income. Therefore, to analyze the trade efficiency and potential as well as the determinants of China's apple industry, this study employed the Stochastic Frontier Gravity Model (hereafter SFGM) on panel datasets from 1997 to 2019 for China and its major trading partners in apple exports. The contribution of this study is reflected in the following aspects: first, the authors checked out the status of China's apple export trade and its share in the international market. Second, to provide an insight on the potential, determinants and efficiency of apple export. Also, we used the SFGM, which combines the gravity model and the stochastic frontier analysis. Third, with our substantial effort, we attempt a gravity model in the fruit industry. Despite the significance and power of the gravity model in the world trade studies, its application in the global fruits industry is relatively rare or missing in the existing literature. Thus, our study designed to fills this gap.

The rest of this study is organized as follows. Section 2 presents the study background. Section 3 reviews the works of relevant literature. Section 4 introduces the empirical model of the SFGM and data used in this study. Section 5 presents the results and discussion. In subsection, we use the SFGM to empirically examine the potential and efficiency of apple export factors. We conclude the study in the last section and propose several policy implications of our study.

2. Study Background

China has been a significant contributor to global apple production and a considerable exporter [17, 18]. Figure 2 illustrates that during the study period, China's apple production has seen a substantial increase, rising from 17.23 million tons (30.76% of global production) in 1997 to 47.57

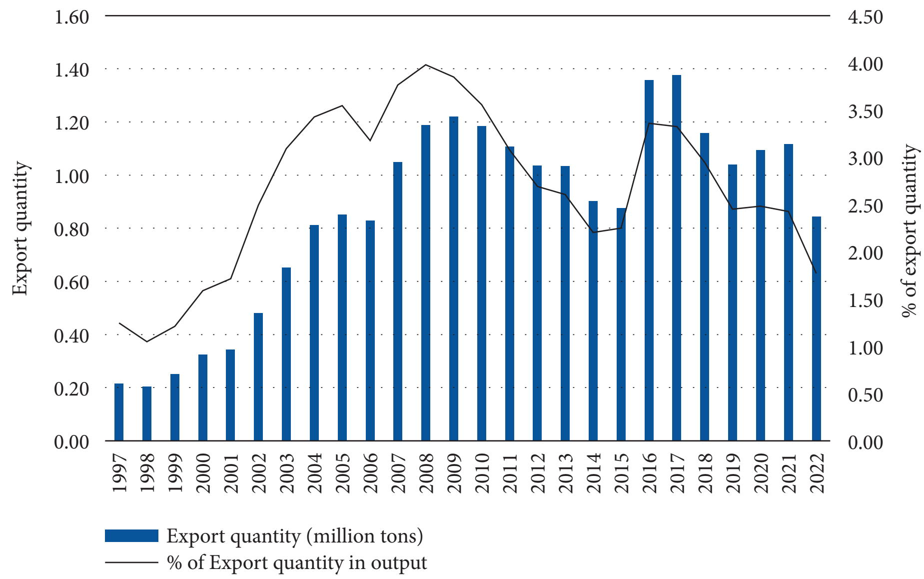

Figure 1: China's apple export quantity and its share in total output. Source: authors' compilation using data from FAOSTAT [9].

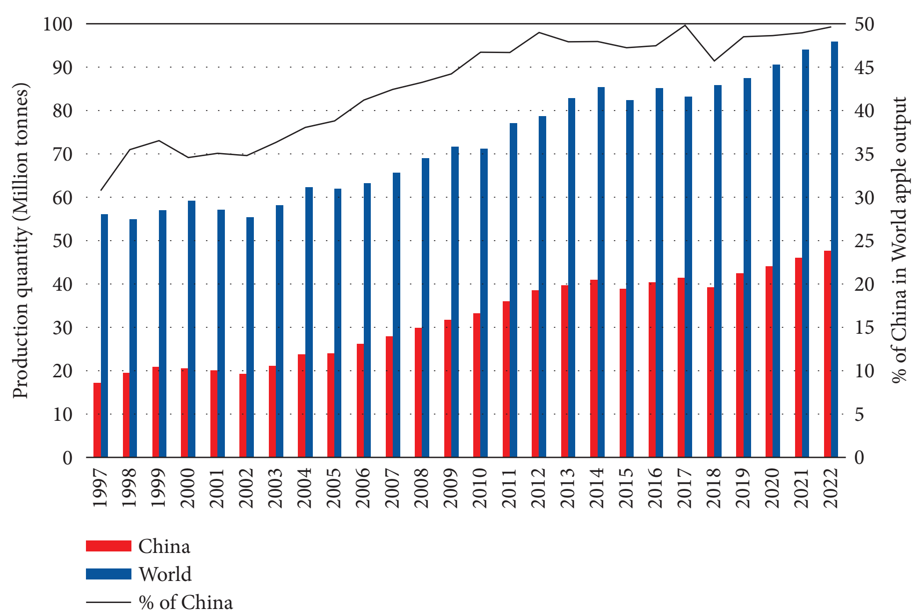

Figure 2: China and world apple output 1997–2022. Source: authors' compilation using data from FAOSTAT [9].

million tons (49.64% of global production)—a remarkable growth of nearly 276.14%.

Figure 3 displays the production quantities of the world's leading apple producers. From 1997 to 2022, China has consistently held the top position as the world's largest apple producer, with an annual average of 30.09 million tons, followed by the USA (4.58), Turkey (2.87), Poland (2.65), Iran (2.46), Italy (2.24), India (1.93), France (1.79), Russia (1.67), and Chile (1.42) million tons.

Figure 4 shows the trend in apple import and export volume in China and the world. Due to the increasing demand for apple consumption, the import and export trade of apples in China and the world is generally increasing [5]. In terms of trade value, the export value of apples in China and the world increased from $101.34 million and $2,811.22 million in 1997 to $1,071.58 million and $6,859.68 million in 2022, respectively. This represents a significant increase in China's apple trade. China's apple export share in global apple exports increased from 3.6% in 1997 to 15.62% in 2022, an increase of nearly 4.34 times. The import value of apples in China and the world increased from $181.38 million and $2,960.17 million in 1997 to $688.5 million and $8,604.18 million in 2022, respectively. Compared to the increase in exports, China's apple import share has experienced slight growth (from 6.13% in 1997 to 8% in 2022), representing an increase of about 15%. It can be seen that China's apples have a relatively large export potential, and the export value of apples will further increase in the future.

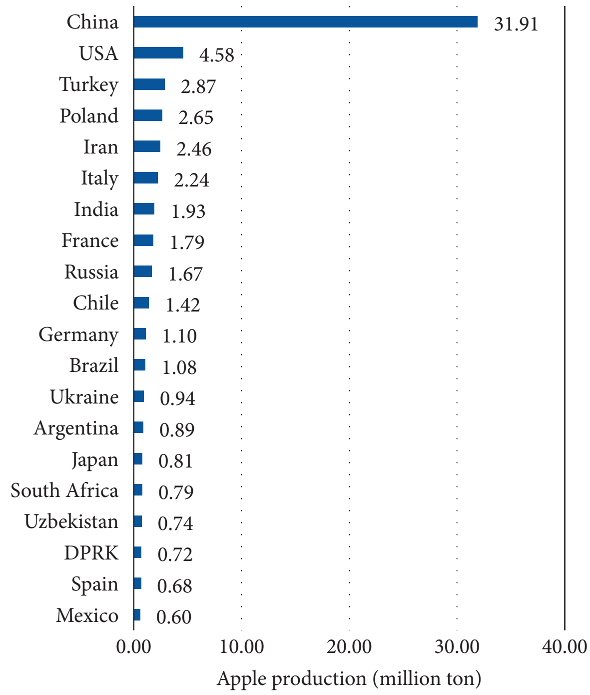

Figure 3: Average apple production of the world top apple producers 1997–2022. Source: authors' compilation using data from FAOSTAT [9].

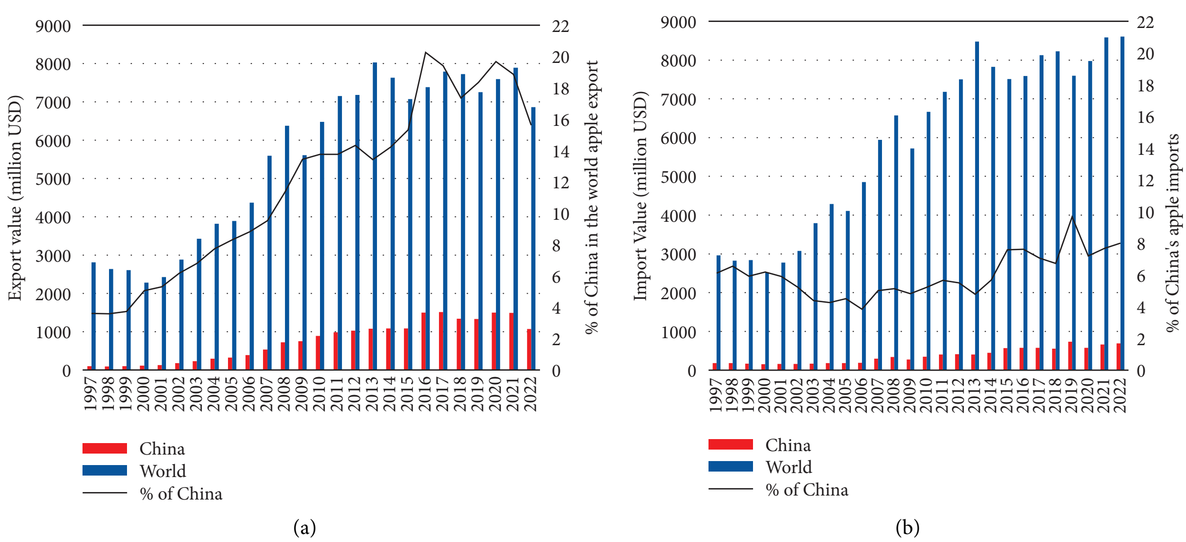

Figure 4: China and the world apple export/import trend 1997–2022. (a) Export. (b) Import. Source: authors' compilation using data from FAOSTAT [9].

Similarly, Mordor Intelligence [6] shows that global demand for apples is increasing due to consumers' growing health concerns. Consequently, this fruit is in high demand among consumers worldwide, particularly in developing countries, the United States, and Europe. Business Wire [19] found that the increase in fresh apple consumption in China can be attributed to a variety of factors. These factors encompass the rising income levels of the population, heightened awareness of health and dietary choices, shifting preferences in food consumption, innovative marketing approaches, and advancements in cold chain logistics. Moreover, the development of e-commerce, fruit chain stores, and WeChat businesses has made fruit consumption more reachable, thus enhancing the consumption value of third- and fourth-tier cities in China [20–22]. China has been the main consumer of fresh apples in the global market, followed by the United States, and the EU [10, 23].

Figure 5 shows that Indonesia, Thailand, Russia and Vietnam are the major export destinations for China's apple export flows. Between 1997 and 2022, these four countries import China's apple worth $275.49 million annually and accounted for 42.54% of the market share. Based on China's

Figure 5: Mean value of China's top apple market 1997–2022 (million USD). Source: authors' compilation using data from FAOSTAT [9].

average export values between 1997 and 2022, the largest trading nations' rank is displayed in Figure 6. Demonstrating that China's top ten apple terminal are as follows: Indonesia (11.43%), Thailand (10.95%), Russia (10.54%), Vietnam (9.62%), Philippines (9.61%), Bangladesh (7.20%), India (5.40%), Kazakhstan (5.38%), Malaysia (4.05%), and Myanmar (3.37%). Furthermore, Figure 6 depicts that the export from China to these nations accounted for 77.55% of China's average apple export to the world market. The yearly mean export flow from China to its top ten key terminal is valued at $502.29 million.

3. Brief Theoretical and Empirical Literature

The idea of gravity model analysis was first applied by Tinbergen in the area of global trade in 1962, and it originated from the gravitational theory of Newton, which was formulated in 1687 [2]. Since then, it has become the most popular empirical tool for trade analysis, and its foundation is based on the prior theoretical literature, on which this paper builds. The gravity equation was initially derived by an economist using the product differentiation model [25], which assumes that consumers perceive differences among products and tend to prefer those that are more distinct. Anderson's model uses preference functions that are either Cobb-Douglas or exhibit a constant elasticity of substitution. Additionally, the model assumes that utility functions for traded and non-traded goods are weakly separable. The gravity model extends this framework to understand the movement of goods, individuals, or information between different locations, with a particular emphasis on the impact of distance and size on these flows. Within the product differentiation model, consumer preferences are influenced by perceived differences among products, leading to the idea that consumers are more likely to choose products from nearby locations due to lower transportation costs and similar preferences [26, 27]. Bergstrand [28, 29] then used monopolistic competition models to examine the microeconomic underpinnings of trade. In his research on 18 industrial countries, Helpman [30] established a connection between the gravity model and monopolistic competition model. Later on, Mátyás [31] proposed the inclusion of dummy variable(s) for trading blocs and time-specific effects into the specification of gravity models.

Ever since the application of the gravity model in international trade analysis, several researches have applied the gravity equation at different levels to explore the determinants and export potential of emerging economies. Many researchers have also incorporated several components into the model. For instance, recently, Ravi Kumar et al. [32] studied the factors affecting Indian rice and its potential using dynamic panel gravity model analysis. They showed that GDP, per capita GDP, trade ties, World Trade Organization (WTO) membership, and exchange rate policy impacted Indian rice exports. Nguyen [33] who applied the SFGM to examine the aggregate effect of "behind-the-border" factors on Vietnam's exports of rice and coffee. The results suggested that Vietnam has great potential to boost its exports of rice and coffee with its main importing nations, especially ASEAN, the European Union (EU) and Comprehensive and Progressive Agreement for Trans-Pacific Partnership.

In a similar vein, Abdullahi & Aluko et al. [33] used the SFGM to examine the determinants, efficiency, and potential of bilateral agri-food exports between Nigeria and the EU from 1995 to 2019. The findings obtained by the scholars show that agri-food trade performance from Nigeria to the EU is influenced by economic size, income, bilateral exchange rate, and distance between Abuja (Nigeria) and the capital cities of trading partners. Furthermore, the results demonstrated that Nigeria is quite inefficient in its agri-food exports to the EU, and there is substantial untapped potential. Similarly, using the SFGM, Atif et al. [35] and Wang et al. [36] found untapped trade potential in Pakistan and China. Moreover, it is commonly stated that there is a huge untapped and unexploited export potential, with a gap between potential and actual exports [37, 38]; Abdullahi et al. [39]. The benefits of agricultural product exports for a country depend on the extent to which the market possesses unexplored potential that can be leveraged [2, 40]. Closing the gap between export potential and existing exports by improving export efficiency provides countries with

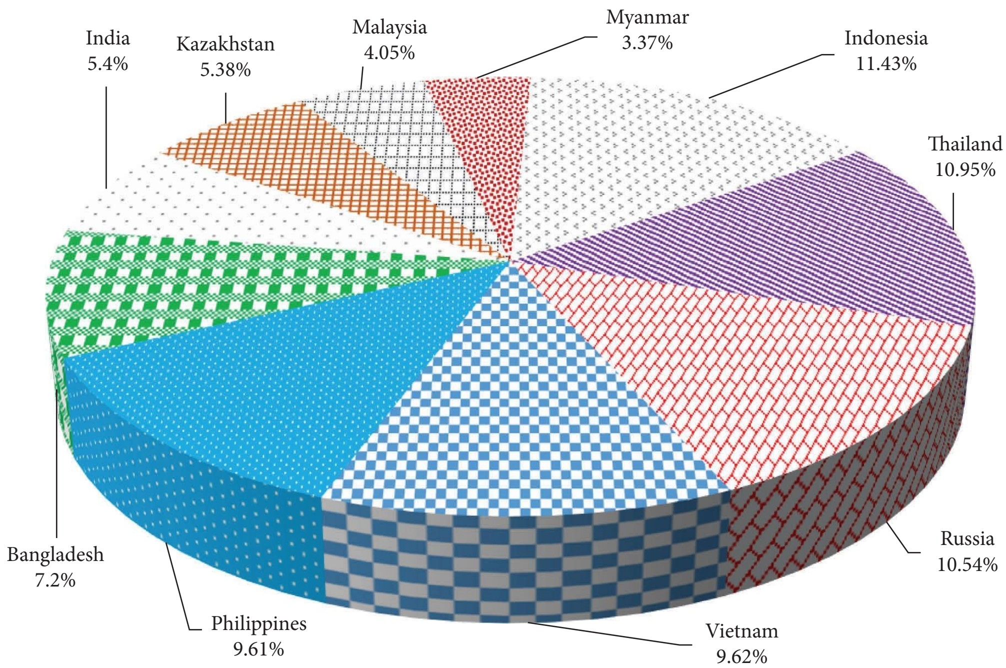

Figure 6: Mean percentage of top ten China's apple exports terminals for the period 1997–2022. Source: authors' compilation using data from UNCOMTRADE [24].

opportunities to enhance export earnings, generate new careers, and nurture their economies [41–43].

Ismaiel Ali Ismaiel et al. [44] conducted a study to examine the drivers of overall Egyptian trade, and specifically Egyptian rice trade in particular with 11 rice-importing partner countries using the traditional augmented gravity model. The results revealed that the export price stimulates Egyptian exports to its trading partners, while distance discourages them. Abdullahi et al. [3] employed three different gravity models (the PPML, Heckman and GLS) to estimate the key drivers of Nigeria's cocoa trade using a panel dataset for the period 1995 to 2018 (24 years) and it 36 importing partners. The results showed that the potential for Nigeria's cocoa export expansion was massive, particularly with developed nations.

Abafita & Tadesse [45] exploited the gravity model by means of panel data from 18 major coffee exporters and 201 importing economies through the period from 2001 to 2015. The results unexpectedly found that the regional trade agreements (RTAs) had no substantial influence on the coffee trade. In a similar vein, Eshetu and Goshu [46] explored the drivers of Ethiopian coffee exports to its major partners using the Generalized Method of Moments (GMM) over the 1998–2016 period. They showed that population, FDI, trade openness, and institutional quality substantially enhance Ethiopian coffee export flow. Meanwhile, the populace of the trading nations, institutional distance, exchange rate, and lagged export volume exacerbate coffee exports.

Shahriar et al. [3] adopt the gravity model in the form of the PPML, the fixed and random effects models, as well as the Heckman model to study the determinants of Bangladesh's leather exports to its major trade partners. This study is based on a panel dataset from 1989 to 2015, which includes a total of 20 carefully chosen largest leather trading economies. They detected that there is great potential for Bangladesh to experience significant growth by exporting to China and exploring network connectivity to enhance leather trade with other nations taking part in the BRI. Bose et al. [47] analyzed the potential reasons for the decline of Oman's fish exports to the EU. They used the dynamic, unbalanced panel data model for the period 2000– 2013. The study employed traditional fixed effects and random effects models and indicated that the decline of Oman's fish exports to the EU markets is mainly affected by domestic export policy and exchange rate fluctuations.

Shahriar & Qian et al. [25] conducted a study using a distinctive dataset spanning 20 years (1997–2016) to analyze China's pork export patterns to its 31 main trading partners. The objective was to identify the key determinants influencing the meat industry's exports in China. The findings indicated that China's membership in the WTO, the BRI, and shared borders are significant factors that impact Chinese pork exports. These results were obtained using the PPML, GLS, and Heckman selection models. Bui and Chen [48] used the gravity model in the form of PPML to examine the drivers of Vietnamese rice exports using a dataset ranging from 2003 to 2014. Their results indicated that GDP, price, exchange rates, and population exhibit a strong association with Vietnamese rice export flows.

Based on the above discussion, it is evident that the existing literature has explored various aspects of agricultural exports. However, a specific investigation into the unexplored opportunities of apple export markets is notably absent. As the world's largest apple producer and consumer, as well as a significant exporter, China's apple trade has a substantial impact on the global apple trade pattern. Furthermore, the apple trade holds considerable economic importance globally, encompassing both domestic and international markets. Despite this, a comprehensive understanding of the factors influencing efficiency and the realization of its full potential remains elusive. With this in mind, we are motivated to bridge this gap by focusing on China's apple exports to major trade partners worldwide. We employed a panel dataset from 1997 to 2019 and utilized the SFGM—a novel approach in the context of apple exports. By doing so, this study provides empirical evidence to guide policy formulation for China's apple export trade.

4. Methodology and Data

4.1. The Gravity Model and the SFGM. Natural and human factors, such as distance, limit bilateral export flows. Both the exporting and importing countries have human characteristics, primarily institutional and infrastructural [49, 50]. The gravity model is an excellent example of this analysis. Newton's law of gravity is the foundation of the gravity model. According to this law, the mass and distance of two bodies are said to be the causes of attraction. Some economists have proposed that bilateral exports between economies are determined by economic size and distance [25]. The gravity model is defined mathematically as follows:

$$\mathrm{EXP}_{ij} = \alpha \frac{\mathrm{GDP}_i . \mathrm{GDP}_j}{\mathrm{Dis}_{ij}}, \tag{1}$$

where $\mathrm{EXP_{ij}}$ is the value of bilateral exports between China and its trading partner j; GDP_i and GDP_j are the GDP of China and its trading economies, respectively. $\mathrm{Dis_{ij}}$ stands for the bilateral distance between China and its trading partner j; α is the constant of proportionality. The linear version of (1) is obtained by taking the natural logarithm of (1). In this study, it may be written as follows for China's apple exports:

$$\begin{aligned}\ln\left(\mathrm{APPEXP_{ijt}}\right) = \beta_0 + \beta_1 \ln\left(\mathrm{GDP_{it}}\right) \\ + \beta_2 \ln\left(\mathrm{GDP_{jt}}\right) + \beta_3 \ln\left(\mathrm{Dis_{ij}}\right) + \varepsilon_{\mathrm{ijt}},\end{aligned} \tag{2}$$

where $\mathrm{APPEXP_{ijt}}$ denotes the value of China's apple export to its trading partners j, j ($j = 1, 2, \ldots, 38$) is for trading partners, t is the time period, i.e., 1997, 1998, . . ., 2022. "ln" stands for a natural logarithm. $\beta_0 - \beta_3$ are the parameter to be estimated. $\varepsilon_{\mathrm{ijt}}$ is the error term.

The traditional gravity model is extended by separating demand and supply-side elements and including literature-identified export stimulating (such as exchange rate, per capita GDP and area) and resistant (such as distance, border and sea) variables [50]. As a result, the model is as follows:

$$\begin{aligned}\mathbf{ln}\left(\mathbf{APPEXP_{ijt}}\right) = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \mathbf{ln}\left(\mathbf{GDP_{it}}\right) + \boldsymbol{\beta}_2 \mathbf{ln}\left(\mathbf{GDP_{jt}}\right) + \boldsymbol{\beta}_3 \mathbf{ln}\left(\mathbf{Dis_{ij}}\right) + \boldsymbol{\beta}_4 \mathbf{ln}\left(\mathbf{Ex_{ijt}}\right) \\ + \boldsymbol{\beta}_6 \mathbf{ln}\left(\mathbf{pcGDP_{jt}}\right) + \boldsymbol{\beta}_7 \mathbf{ln}\left(\mathbf{Area_j}\right) + \boldsymbol{\gamma}_1\left(\mathbf{Border_{ij}}\right) + \boldsymbol{\gamma}_2\left(\mathbf{Sea_{ij}}\right) + \varsigma_{\mathbf{ijt}},\end{aligned} \tag{3}$$

where $\mathrm{Ex_{ijt}}$ stands for the bilateral exchange rate between China and its trading partner j, $\mathrm{pcGDP_{jt}}$ represent the per capita GDP of the two countries involved in trade for a t year, Area_j represents agricultural land area, $\mathrm{Border_{ij}}$ is 1 if country j has a common border with China, otherwise, 0. $\mathrm{Sea_{ij}}$ is a dummy variable with a value of 1 if country j has sea border, otherwise 0. $\beta_0 - \beta_7$, γ_1 and γ_2 are the parameter to be estimated. ς_{ijt} is the error term. All other variables are as defined earlier.

The description in the (3) confronts two significant difficulties. These are heteroscedasticity, or the fact that the error term is not normally distributed, in which the error term is linked with unobserved factors. Genuinely, it has a non-negative methodical component as well as a random component [52, 53]. The trade boost potential is expressed in terms of the sample average rather than the greatest amount possible for a given pair of trading partners, which is the method's fundamental flaw. Because the gravity model's predictive capacity reduces when the year of the input values rapidly deviates from the sample average, calculating trade potential versus average expected values might be challenging [13]. The SFGM is useful for correcting the flaws in the standard gravity model.

Aigner et al. [54] and Meeusen & Van Den Broeck [55] developed the stochastic frontier analysis (SFA) model to analyze technical efficiency in manufacturing. The output was modeled as a function of the inputs and an error term. The stochastic error term is made up of a production inefficiency element and a random component. The last part of the error may be fixed if the right policies are executed. The SFA can be utilized to express the export frontier and can measure the extent to which actual exports fall below the maximum potential exports. The SFGM offers several advantages over traditional gravity models. By incorporating a stochastic frontier approach, it allows for a more accurate estimation of the parameters governing spatial interactions. This model also enables the identification of factors contributing to variations in efficiency across locations, providing valuable insights for policy interventions aimed at improving efficiency in trade, migration, or other flows between locations [27]. Additionally, the stochastic frontier gravity model allows for the estimation of both technical efficiency and allocative efficiency, offering a more comprehensive understanding of spatial interactions and their determinants.

In this paper, the SFA is introduced into the gravity equation to account for changes in trade with trading partners. This approach allows for the freedom to choose the optimal level of trade between countries (trade frontiers) in the analysis, and it also allows the actual size of a country's trade to be harmonized with the forecasted frontier values of the importing country in order to examine the maximum size of trade [33]. To solve the matching difficulties of heteroscedasticity and normalcy of the error component linked with the classic method (gravity equation), Kalirajan & Singh [49] suggested using this paradigm to study trade flows between countries. The error term of the standard gravity model has been separated into two parts: an inefficiency element and a random component. SFA is turned into SFGM as follows, after being incorporated into our extended gravity model in (4):

$$\begin{aligned}\ln\left(\mathbf{APPEXP}_{ijt}\right) &= \beta_0 + \beta_1 \ln\left(\mathbf{GDP}_{it}\right) + \beta_2 \ln\left(\mathbf{GDP}_{jt}\right) + \beta_3 \ln\left(\mathbf{Dis}_{ij}\right) + \beta_4 \ln\left(\mathbf{Ex}_{ijt}\right) \\ &\quad + \beta_6 \ln\left(\mathbf{pcGDP}_{jt}\right) + \beta_7 \ln\left(\mathbf{Area}_j\right) + \gamma_1\left(\mathbf{Border}_{ij}\right) + \gamma_2\left(\mathbf{Sea}_{ij}\right) + \varepsilon_{ijt} - \mathbf{V}_{ijt}.\end{aligned} \tag{4}$$

In this study, we used the post estimate command created by Battese & Coelli [56] in Stata to project the point estimation of export efficiency, as shown in (5), after obtaining the parameter estimates of the frontier model in (4). The gravity model's coefficients were then utilized to calculate the export potential.

$$E\left[\mathrm{Exp}\left(-V_{ijt}\right) \mid e_{ijt} + V_{ijt}\right] = \frac{1 - \phi\left[\sigma_* + \Upsilon\left(e_{ijt} + V_{ijt}\right)/\sigma_*\right]}{1 - \phi\Upsilon\left(e_{ijt} + V_{ijt}\right)/\sigma_*} \exp\left[\Upsilon\left(e_{ijt} + V_{ijt}\right) + \frac{\sigma_*^2}{2}\right], \tag{5}$$

where $\phi(.)$ designates the density function. The assessed efficiency (γ) from (5) can fluctuate from 0% to 100%. In this case, an efficiency value of 0% indicates inefficiency, and greater trade is possible with the trade variables in (4). On the other hand, an efficiency score of 100% demonstrates excellent efficiency, meaning that the actual trade perfectly aligns with the potential trade.

4.2. Sample Size and Data. In this study, we collected a 26-year dataset, spanning 1997 to 2022, and it consists of 38 countries, which were selected based on their trade history with China and the availability of data. The dataset comprises a total of 988 observations ($t * j = 26 * 38 = 988$). Table 1 presents this study's key variables and data sources, while Table 2 shows the descriptive statistics of the variables. Except for dummy variables, the natural logarithms were taken for all variables in the model. The data is balanced, and none of the variables deviate significantly from the normal distribution. There is also no extensive range among the lowest and highest values between sample observations.

5. Empirical Results and Discussion

5.1. Descriptive Statistics and Correlation Matrix. Table 2 offers the summary statistics of our study variables. All variables have a reasonable range between the minimum and maximum observations. This indicates a degree of variability that is neither extremely narrow nor exceptionally wide. This moderate range suggests that the data exhibit some level of dispersion or spread, allowing for meaningful comparisons and analyses without being excessively constrained or overly scattered. Moreover, the mean and the standard deviation of the study variables suggest that each variable's data point within the dataset deviate moderately from the mean, providing insight into the spread of the data distribution. Analyzing the distribution of the variables within this range can help identify patterns and relationships with other variables, enhancing our understanding of the phenomenon being studied.

To identify multicollinearity among the variables used in the model, we present the results of the correlation matrix of the variables, as shown in Table 3. It also provides a quick overview of the association among the variables. $\mathrm{LnAppExp}_{ijt}$ is positively linked with the explanatory variables (LnGdp_{it}, LnGdp_{jt}, LnArea_{jt}, $\mathrm{LnExchr}_{ijt}$, Border_{ij}). The correlation coefficients of all the variables are moderate, with the highest being 0.533. In addition, Gujarati (2019) indicated that multicollinearity is present when the correlation coefficient exceeds 0.8. Hausman (2001) suggests that a correlation coefficient below 0.8 produces more accurate results. Further multicollinearity estimation was employed to compute the variance inflation factor (VIF) and tolerance levels (1/VIF) of the independent variables. VIF values below 10 and tolerance figures exceeding 0.1 are deemed satisfactory. The analysis findings indicate that the equation remains unaffected by multicollinearity, as the VIF values and tolerance levels for all parameters lie within the appropriate range. This suggests that there is no multicollinearity among the variables we used in the SFGM.

5.2. Factors Affecting China's Apple Exports 1997–2022. Table 4 presents the outcomes of the maximum likelihood estimate of the SFGM and the inefficiency model. The results of the extended gravity model with the stochastic frontier

Table 1: Description and sources of data used in this study.

Variables	Description	Unit	Source
$AppExp_{ijt}$	Bilateral apple export	USD	UNCOMTRADE
Gdp_{it}	Income of China	USD	World bank
Gdp_{jt}	Income of importing country	USD	World bank
Dis_{i_j}	Distance between Beijing and trading country's capital city	Kilometers	CEPII
$PcGdp_{jt}$	Per capita income of importing country	USD	World bank
$Exchr_{ijt}$	Bilateral exchange rate	Yuan/J's currency	UNCTAD
$Area_{jt}$	Agricultural land area	Hectares	FAOSTAT
$Border_{ij}$	Common border	Binary	CEPII
Sea_j	Access to sea port	Binary	CEPII

Source: authors' compilation.

Table 2: Descriptive statistics of the variables.

Variables	Mean	Std. Dev.	Min	Max
$LnAppExp_{ijt}$	14.408	3.513	−27.631	19.751
$LnGdp_{it}$	29.171	1.000	27.592	30.519
$LnGdp_{jt}$	25.420	2.095	20.542	30.867
$LnDis_{i\_j}$	8.440	0.607	6.695	9.607
$LnPcGdp_{jt}$	8.770	1.771	4.506	11.597
$LnArea_{jt}$	8.245	3.255	−0.416	13.726
$LnExchr_{ijt}$	0.907	3.020	−3.701	8.186
$Border_{ij}$	0.282	0.450	0.000	1.000
Sea_j	0.872	0.333	0.000	1.000

Source: authors' calculation.

Table 3: Correlation matric of the variables.

S/no.	Variables	1	2	3	4	5	6	7	8	9	VIF	1/VIF
1	$LnAppExp_{ijt}$	1.000										
2	$LnGdp_{it}$	0.174	1.000								1.25	0.803
3	$LnGdp_{jt}$	0.210	0.256	1.000							2.84	0.353
4	$LnDis_{i\_j}$	−0.148	0.053	0.418	1.000						1.79	0.557
5	$LnPcGdp_{jt}$	−0.013	0.257	0.533	0.469	1.000					3.73	0.268
6	$LnArea_{jt}$	0.095	0.032	0.253	−0.013	−0.393	1.000				2.25	0.445
7	$LnExchr_{ijt}$	0.175	0.052	−0.331	−0.533	−0.699	−0.385	1.000			2.77	0.360
8	$Border_{ij}$	0.075	−0.036	−0.217	−0.488	−0.319	0.228	0.484	1.000		1.64	0.608
9	Sea_j	−0.034	0.031	0.459	0.347	0.369	−0.214	−0.386	−0.442	1.000	1.71	0.584

Source: authors' calculation.

Table 4: Maximum likelihood estimates from the SFGM.

	Coefficient	Standard error	*p* value
$LnGdp_{it}$	0.281***	0.073	0.001
$LnGdp_{jt}$	1.021***	0.069	0.001
$LnDis_{i\_j}$	−1.606***	0.125	0.001
$LnPcGdp_{jt}$	−0.308***	0.056	0.001
Export inefficiency components			
$LnArea_{jt}$	1.558**	0.660	0.018
$LnExchr_{ijt}$	−1.351**	0.678	0.046
$Border_{ij}$	9.493**	4.317	0.028
Sea_j	6.700**	4.070	0.010
Constant	−49.426***	19.031	0.008
σ_u	22.132***	4.273	0.001
σ_v	0.229***	0.038	0.001
λ	0.999		
LR	1562.324		
Wald x^2	32152.940		
Number of observations	932		
Prob > x^2	0.001		

Note. *** and ** show significance at the 1% and 5% levels, respectively. Due to the zero trade value in some years, the number of observations is 932. Source: authors' calculations.

specifications follow the assumptions of the gravity model. It can be seen that the GDP of China and that of its apple-importing nations are positively associated with apple export flows at a 1% significance level. The positive coefficients of GDP show that a 1% increase in GDP for both China and its trading partner enhances bilateral apple exports by 0.28% and 1.02%, respectively. This indicates a significant impact of economic growth on apple exports, highlighting the importance of economic factors in shaping bilateral trade relationships and export performance. Our results confirm the findings of Kea et al. [57]; Abdullahi & Shahriar et al., [3] and Boadu et al. [2]. Additionally, with a p value of 0.001, the bilateral distance has a detrimental effect on China's apple exports. The coefficient of Dis_{i_j} is unfavorable and statistically significant indicating that a percentage increase in distance reduces China's apple exports by nearly 1.61%. This result aligns with the findings of Suroso et al. [12]; who demonstrated the deterrent effect of distance on China's tea exports, as well as Abdullahi et al. [27]; who highlighted the negative impact of distance on agricultural exports in China.

The income variable ($\mathrm{LnPcGdp}_{jt}$) for the importing nations is statistically significant with negative coefficients and at a 1% statistical significance level, implying that a percentage decrease in the per capita GDP of apple-importing nation is anticipated to exacerbate China's apple export flows by 0.31%. The per capita GDP of the exporting country signifies the consumption capacity of the exporting nation, while in the case of the importing nation; the per capita GDP shows the import ability of the importing nation. In light of this, we anticipated that this variable would favorably affect China's apple export flows. The outcome of this study is consistent with past research findings that documented a negative relationship between per capita income and trade flows. For example, Hassan [58] noted the "unexpected negative sign" of South Asian countries' per capita GDP. Some scholars, such as Assane & Chiang [59]; used the gravity framework to evaluate the trade flows of the Economic Community of West African States (ECOWAS) and showed negative signs for per capita GDP. In another work, Shahriar et al. [3] proposed that nations with similar income distributions trade more with one another. Moreover, it has been reported that when a negative effect of per capita GDP is found in both the exporting and importing nations, it could be attributed to various factors such as economic recessions, exchange rate fluctuations, supply chain disruptions, trade barriers, policy changes, and commodity-specific factors. These negative indicators signal broader economic challenges and disruptions that affect trade and economic performance on a global scale [32]. Understanding the underlying reasons for negative per capita GDPs requires considering a range of economic, political, and external factors that impact trade dynamics and overall economic health in both nations [14, 34].

The findings showed that the effect of importing nations agricultural land area (LnArea_{jt}) on China's apple export efficiency turns out to be positive and with a p value of 0.018. This indicates that an increase in the LnArea_{jt} of the importing country could worsen China's apple export efficiencies by 1.56%. This exacerbation is statistically significant at the 5% level, indicating a meaningful impact. The reason behind this could be heightened competition as domestic production of apples or similar fruits increases in the importing country. This increased competition may lead to reduced market share, lower prices, or higher marketing costs for China's exported apples, contributing to export inefficiencies. Similarly, Zhang et al. [8] studied the contributory factors for increased fruit production in China from 1978 to 2016. The study found that except for the increase in apple yield which mainly depends on yield per unit, the increase in the yield of citrus, pears, grapes and bananas mainly depends on the expansion of the planting area.

Based on the inefficiency model, export inefficiency is the response variable. The literature suggests that a negative sign associated with a specific variable indicates a positive effect on export efficiency. The coefficient of $\mathrm{LnExchr}_{ijt}$ is negative and significant at a 5% significance level ($p = 0.046$). This shows that the appreciation of China's local currency (RMB) relative to that of importing countries reduces the transaction cost of the exporting nation, thereby enhancing the export efficiency of China's apple [60, 61]. Abdullahi & Huo et al. [51] document a similar result for Nigeria's agri-food trade.

The coefficient of the dummy variable (Border_{ij}) is statistically significant at a 5% level ($p = 0.028$) and exhibits a positive effect. Drawing from this result, we can infer that those countries that have territorial adjacency with China rise the country's apple exports inefficiency to those countries by 9.49 units. According to Abdullahi & Shahriar, et al. [3]; the existence of a shared border between countries can offer potential trade advantages, such as increased proximity and market accessibility. However, this condition can also give rise to certain challenges that impede export efficiency, including transportation expenses, trade barriers, political tensions, and logistical intricacies.

Finally, the coefficient of Sea_j indicates that when an importing country does not have access to a seaport, China's apple export efficiency would decrease by 6.70 units. This result is statistically significant at a 5% level ($p = 0.010$), and it also suggests that due to lower trade costs, China is more likely to export apples to countries with seaports. Several studies have also confirmed that trade costs can impact a country's competitive advantage in exports [62–64]. Landlocked countries, compared to non-landlocked countries, face disadvantages in trade due to their geographic location [50, 57, 65].

5.3. Robustness Check. To confirm the robustness of our estimation, we generate the gravity model parameters calculated for the composed error term variance, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and the ratio of the standard deviation of the inefficiency component to the standard deviation of the random error component, $\lambda = \sigma_u^2/\sigma^2$. The λ values indicate the fitness of the SFA across our estimated model. The value of 0.999 for λ shows that variation in output is accounted for by technical efficiency (99.90%). Furthermore, an extra test for the

Table 5: Technical efficiency (TE) scores of China's apple exports (1997–2022).

Countries with less 50% efficiency		Countries with more than 50% efficiency	
Country	TE (%)	Country	TE (%)
Bangladesh	0.490	Philippines	0.626
Hong Kong	0.482	Malaysia	0.600
Kazakhstan	0.479	Vietnam	0.593
Russia	0.448	Nepal	0.570
Canada	0.426	Indonesia	0.567
UAE	0.422	Thailand	0.546
Suriname	0.399	Sri Lanka	0.545
Norway	0.396	Singapore	0.523
Mongolia	0.383		
Brunei Darussalam	0.372		
Macao	0.368		
Saudi Arabia	0.366		
Bahrain	0.352		
Qatar	0.345		
Myanmar	0.331		
Kenya	0.322		
Kyrgyzstan	0.310		
Netherlands	0.308		
Laos	0.306		
Kuwait	0.304		
United Kingdom	0.294		
Oman	0.285		
North Korea	0.269		
India	0.265		
Spain	0.255		
Pakistan	0.238		
Ghana	0.218		
Cambodia	0.216		
Sweden	0.209		
USA	0.142		
Italy	0.135		

Source: authors' calculations.

presence of technical efficiency (TE) in the model is carried out via a one-sided likelihood ratio (LR) test of the null hypothesis, H_0: $\sigma_u^2 = 0$, against the alternative, H_1: $\sigma_u^2 > 0$. Furthermore, the LR statistic is 1562.324, which is much higher than the critical value of 2.706. As a result, the null hypothesis of no export inefficiency is rejected. In other words, the robustness test presented in Table 4 validates the SFGM estimations.

5.4. Efficiency and Potential of China's Apple Exports (1997–2022). Table 5 presents the technical efficiency scores of China's apple exports, while Table 6 reports their potential scores. On average, between 1997 and 2022, the efficiency of the countries in this study is 33.71%, which is below the average value of 50%. In short, it is safe to say that China's apple exports are far from efficient. An efficiency score of over 50% indicates that China is relatively efficient in exporting apples, whereas a score below 50% suggests that China's efficiency in exporting apples is low. Although some countries, such as the Philippines (62.6%), Malaysia (60.0%), Vietnam (59.3%), Nepal (57.0%), Indonesia (56.7%), Thailand (54.6%), Sri Lanka (54.5%), and Singapore (52.3%), achieved relatively high efficiency, none of the countries in this study reached 100% efficiency. This could be attributed to factors such as favorable trade agreements, efficient supply chains, market demand, or competitive pricing strategies that make exporting apples to those countries more efficient for China. Furthermore, these countries are the only ones that recorded efficiency scores above 50%, while most of the countries in this study showed relatively poor efficiency. Interestingly, despite their economic and market sizes, Italy, the USA, and Sweden were the least efficient countries for China's apple exports during the study period, with efficiency scores of 13.5%, 14.2%, and 20.9%, respectively. One possible reason for this is that due to the relatively high level of economic development and per capita income in these countries, they have higher requirements for the quality and variety of imported Chinese apples [6, 66]. Another reason may be attributed to various factors such as, trade barriers, transportation costs, market dynamics, or lower demand for Chinese apples in the Canadian market.

Table 6 reveals that the top countries with high export potentials are India (19.53), the USA (19.53), Russia (18.01), United Kingdom (17.85), Indonesia (17.85), Philippines (17.81), Hong Kong (17.81), Thailand (17.78), Vietnam (17.70), Italy (17.62), North Korea (17.59), etc. These potentials exist due to factors such as market size, market

Table 6: Export potential (EP) of China's apple exports (1997–2022).

Country	EP
India	19.531
USA	19.527
Russia	18.006
United Kingdom	17.853
Indonesia	17.852
Philippines	17.812
Hong Kong	17.807
Thailand	17.776
Vietnam	17.702
Italy	17.624
North Korea	17.591
Bangladesh	17.557
Pakistan	17.440
Spain	16.993
Malaysia	16.841
Canada	16.814
Saudi Arabia	16.699
Netherlands	16.640
Kazakhstan	16.356
Sweden	16.354
Singapore	16.247
UAE	15.971
Norway	15.885
Mongolia	15.597
Nepal	15.431
Sri Lanka	15.333
Macao	15.246
Kuwait	14.971
Cambodia	14.925
Myanmar	14.915
Oman	14.664
Qatar	14.627
Laos	14.573
Kenya	14.524
Kyrgyzstan	13.926
Ghana	13.679
Bahrain	13.628
Brunei Darussalam	13.589
Suriname	10.262

Source: authors' calculations.

proximity (India, the USA, Russia, United Kingdom, Hong Kong, Thailand, Vietnam, and North Korea), and cultural and language similarities (Hong Kong, Vietnam, North Korea, and Thailand). On the other hand, Suriname (10.26), Brunei Darussalam (13.59), Bahrain (13.63), and Ghana (13.68) are the countries with the least export potential for China's apple industry. It is essential to note that no country recorded a single-digit potential value in this study. Based on the average value for all countries between 1997 and 2022, China had an untapped export potential of 628.77 with its trading partners in apple exports. China's apple exports are less than optimal in all the countries considered in this study.

6. Conclusion and Policy Recommendations

As China holds the position of the world's largest apple producer, the nation's apple exports play a vital role in generating income from apple production and relieving pressure on the domestic apple market. In light of this context, this study employs a Stochastic Frontier Gravity Model (SFGM) to dissect the complexities of China's apple exports, offering a nuanced understanding of the factors shaping trade flows from 1997 to 2022 across 38 countries. Our findings illuminate the significant influence of economic growth in both China and its trading partners on enhancing apple export volumes, with GDP increases positively correlated with export flows. Conversely, the study reveals the constraining impact of geographical distance and the unexpected negative association between the per capita GDP of importing nations, underscoring the multifaceted nature of trade dynamics. The appreciation of China's currency is identified as a key factor in reducing transaction costs and bolstering export efficiency, while increased agricultural land area in importing countries introduces heightened competition, dampening export performance. Geographical and infrastructural advantages, such as shared borders and seaport access, emerge as pivotal elements in determining export efficiency. The analysis also uncovers significant untapped export potential in several countries, highlighting opportunities for strategic market expansion. The study's limitations and proposed future research directions pave the way for a deeper exploration of global trade intricacies, offering valuable insights for policymakers and exporters aiming to optimize China's agricultural export landscape in a rapidly evolving global market.

Based on the findings of the study, several key policy suggestions can be made to optimize China's apple export strategy. Policymakers should consider strategies for currency management to ensure that the Renminbi (RMB) remains competitive. This can be achieved by enhancing export efficiency, which includes reducing transaction costs for international buyers. Additionally, China could benefit from negotiating and entering into trade agreements that specifically address and mitigate the negative impacts of distance on trade flows. This can be done through terms that lower tariffs, simplify customs procedures, and enhance logistical connectivity with distant markets. The identification of countries with untapped export potential suggests a need for targeted marketing and trade initiatives. These initiatives should focus on expanding market presence through promotional activities, trade fairs, and business-to-business meetings. To address competitive challenges, China should invest in research and development to improve apple quality, diversify varieties, and implement sustainable farming practices. Moreover, improving infrastructure and logistics in regions with shared borders and seaports can significantly boost export efficiency, reducing costs and delivery times. Understanding and adapting to market preferences, as well as implementing trade facilitation measures such as digitalization of trade procedures and reducing bureaucratic hurdles, will further enhance China's apple exports. By adopting these policy suggestions, China can effectively navigate the complexities of the global trade environment. This will maximize the potential of its apple exports and sustain growth in this vital agricultural sector.

The study presents several limitations, including a constrained data scope that may not fully capture the most recent trends, such as the effect of the COVID-19 pandemic on trade. The reliance on the stochastic frontier gravity model, while robust, may overlook complexities such as informal trade barriers and cultural influences on trade dynamics. Additionally, geopolitical intricacies and specific trade policies that can significantly impact trade flows might not be adequately considered. The analysis also might not fully account for market demand variables, including consumer preferences and brand recognition, which are crucial in determining export efficiency and potential in various markets.

For future research, it would be insightful to investigate the impacts of global disruptions, notably the COVID-19 pandemic, on trade patterns and recovery strategies. Incorporating micro-level data, such as consumer preferences and brand presence, could offer deeper insights into market dynamics. A detailed evaluation of trade policies and their effects on exports, along with comparative analyses of other export commodities, could reveal broader trade challenges and opportunities. Moreover, exploring the roles of technological advancements and environmental sustainability practices in agriculture could provide valuable perspectives on enhancing the global competitiveness of China's agricultural exports [67–76].

Data Availability

Data used in the study are available upon reasonable request to the corresponding author.

Ethical Approval

This paper complied with the code of ethics.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Biao Ke conceptualized the study, curated the data, performed formal analysis, funded the acquisition, proposed the methodology, was responsible for software, wrote the original draft, and wrote, reviewed, and edited the study. Qiangqiang Zhang conceptualized the study, curated the data, performed formal analysis, funded the acquisition, proposed the methodology, administered the project, was responsible for software, wrote the original draft, and wrote, reviewed, and edited the study..

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