A Study on Measuring the Cold Chain Logistics Efficiency of Fresh Agricultural Products in Shandong Province Based on Dea-Malmquist Model

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Abstract. Shandong Province has evolved into a prominent production hub for fresh agricultural products, largely due to its distinctive geographical attributes and climatic conditions. The study of the cold chain logistics efficiency of fresh agricultural products in Shandong Province has the potential to facilitate the expansion of the market for agricultural products, increase farmers' income, drive the development of related industries, and contribute to the revitalisation of the countryside. The DEA model and Malmquist index were employed to analyse the static and dynamic changes in the cold chain logistics of fresh agricultural products in Shandong Province. The data for the period 2019-2023 was analysed and compared with the national data set. The study reveals that, when analysed from a static perspective, the cold chain logistics efficiency of Shandong Province is generally lower than the national level. This is mainly due to a lower pure technical efficiency, although the province outperforms the nation in terms of scale efficiency. The improvement of fresh agricultural products' cold chain logistics efficiency in Shandong province is more stable in terms of dynamic changes. It is therefore recommended that the province should proactively promote technological innovation and application, reinforce personnel training, optimise cold chain logistics infrastructure and enhance scale operations.

Keywords: Shandong;Fresh Agricultural Products; Cold Chain Logistics Efficiency; Data Envelopment Analysis

1 Introduction

Cold chain logistics is essential for reducing losses and maintaining the freshness and safety of agricultural products, boosting their value and increasing farmers' income. It also plays a key role in disaster relief, vaccine, and medication transportation. Shandong is promoting cold chain facility construction, with its climate and proximity to economic hubs aiding agricultural distribution. The rise of fresh e-commerce highlights the importance of cold chain logistics. Environmentally-friendly technologies in cold chain logistics reduce energy consumption and emissions, supporting sustainable development. However, rural areas still face infrastructure deficiencies, and a lack of unified standards affects product quality.

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The current research on the efficiency of cold chain logistics for agricultural products conducted by global scholars tends to adopt an overly broad or narrow scope. On the one hand, there are studies that evaluate the efficiency of cold chain logistics on a nationwide scale. On the other hand, there are studies that evaluate the efficiency of cold chain logistics in a specific city. Domestic scholar Zhang Lu employed the Data Envelopment Analysis (DEA) model and other analytical techniques to assess the spatial efficiency of cold chain logistics for fresh agricultural products in China. [1]. Zhao Chengxia employed the DEA and Tobit regression models to examine the efficacy of cold chain logistics for fresh agricultural products in the western region, emphasising the necessity for China to reinforce assembly levels and enhance resource utilisation[2]. Ma Lanhua employed the analytic hierarchy process to analyse Fuzhou. The conclusions and recommendations included the suggestion that third-party cold chain logistics enterprises should be developed vigorously, market supervision should be strengthened, and the formulation of cold chain logistics industry standards should be accelerated[3]. Hou Xiangjie employed the DEA model to assess the efficiency of cold chain logistics for fresh agricultural products in the Beijing-Tianjin-Hebei region. Based on this analysis, he proposed enhancing the management of cold chain logistics, promoting the development of the tertiary industry in the region, and making optimal use of regional advantages[4]. Yin Yue used the DEA model to investigate the efficiency of cold chain logistics in the eastern region of China. She proposed a three-fold approach: regional development promotion, infrastructure construction, and external environment management, aiming to improve cold chain logistics for fresh agricultural products in this region[5].

To conclude, research on cold chain logistics for agricultural products is still in its infancy, and there is a paucity of research on the efficiency of cold chain logistics for fresh agricultural products in Shandong Province. It would therefore be beneficial to conduct an analysis and evaluation of the situation in Shandong, with a view to accelerating the development of the region's cold chain logistics system and providing a useful point of reference for the establishment of a complete cold chain system.

2 Measurement of Cold Chain Logistics Efficiency for Fresh Produce

2.1 Research Methods: DEA Model and MALMQUIST INDEX

DEA Model. Data Envelopment Analysis (DEA) is a method that analyzes the input and output data of Decision-Making Units (DMUs) to determine their efficiency. It ranks the efficiency indices of all DMUs to identify the most effective unit. DEA can be categorized into three models: BCC, CCR, and DEA-Malmquist index model[6]. The BCC model considers variable returns to scale, affecting technical efficiency measurement when some units are not operating at their optimal scale.

BCC model principle:

$$\min\theta$$

$$\text{s.t.}\sum_{j=1}^{n}\lambda_j y_j - s^+ = \theta x_0$$

$$\sum_{j=1}^{n}\lambda_j y_j - s^- = \theta y_0$$

$$\sum\lambda_j = 1, j = 1,2,\ldots n$$

$$s^+ \geq 0, s^- \leq 0$$

Malquist Index. This productivity index can be broken down into efficiency changes oriented towards inputs (EFFCH) and technical efficiency (TECHCH), which can be broken down into scale efficiency (SECH) and pure technical efficiency (PECH):

$$MPI_I^G = (EFFCH_I)\cdot(TECHCH_I^G)=\left(\frac{E_I^{t+1}(x^{t+1},y^{t+1})}{E_I^t(x^t,y^t)}\right)\cdot\left[\left(\frac{E_I^t(x^t,y^t)}{E_I^{t+1}(x^t,y^t)}\right)\cdot\left(\frac{E_I^t(x^{t+1},y^{t+1})}{E_I^{t+1}(x^{t+1},y^{t+1})}\right)\right]^{1/2}$$

$$SECH = \left[\left(\frac{E_{vrs}^{t+1}(x^{t+1},y^{t+1})/E_{crs}^{t+1}(x^{t+1},y^{t+1})}{E_{vrs}^{t+1}(x^t,y^t)/E_{crs}^{t+1}(x^t,y^t)}\right)\cdot\frac{E_{vrs}^t(x^{t+1},y^{t+1})/E_{crs}^t(x^{t+1},y^{t+1})}{E_{vrs}^t(x^t,y^t)/E_{crs}^t(x^t,y^t)}\right]^{1/2}$$

$$PECH=\frac{E_{vrs}^{t+1}(x^{t+1},y^{t+1})}{E_{crs}^t(x^t,y^t)}$$

2.2 Indicator Selection and Data Sources

In consideration of the accessibility and scientific rigour of the data, as well as the findings of domestic and international scholars[7-8] , This paper uses four input indicators to evaluate the efficiency of cold chain logistics for fresh agricultural products in Shandong. These include investment in fixed assets in logistics, number of employees in the cold chain, total distance traveled, and total capacity of cold storage. The output indicators include total logistics volume of agricultural products, turnover of agricultural cold chain logistics, and the freight volume of agricultural cold chain. The data is analyzed using both domestic and international efficiency of cold chain logistics for fresh agricultural product.

The article uses data from 31 provinces (excluding Hong Kong, Macao and Taiwan) for a total of 5 years from 2019 to 2023. The data is mainly from the China Statistical Yearbook, the statistical yearbooks of each province, the China Cold Chain Logistics Development Report, and the China Cold Chain Logistics Network.

3 Analysis of Result

3.1 Static Comparison of the Efficiency of Cold Chain Logistics for Fresh Agricultural Products

A DEA-BCC model based on input orientation was constructed, and the DEAP2.1 software was used to calculate and analyse the cold chain logistics efficiency of fresh agricultural products in 31 provinces from 2019 to 2023. The static efficiency was discussed and studied from the perspectives of comprehensive technical efficiency, pure technical efficiency and scale efficiency benefits.

Comprehensive Technical Efficiency Comparison of Cold Chain Logistics for Fresh Agricultural Products. As shown in Figure 1, the mean comprehensive technical efficiency of cold chain logistics for fresh agricultural products in Shandong over the past five years has ranged between 0.4–0.6, the lowest among China's eastern coastal provinces. In contrast, provinces like Zhejiang, Tianjin, and Liaoning have efficiencies exceeding 0.9. Shandong's cold chain logistics still requires significant improvement, with infrastructure distribution uneven and lacking unified standards. Outdated facilities, a shortage of professionals, poor management, and low marketization hinder progress, indicating substantial room for enhancement.

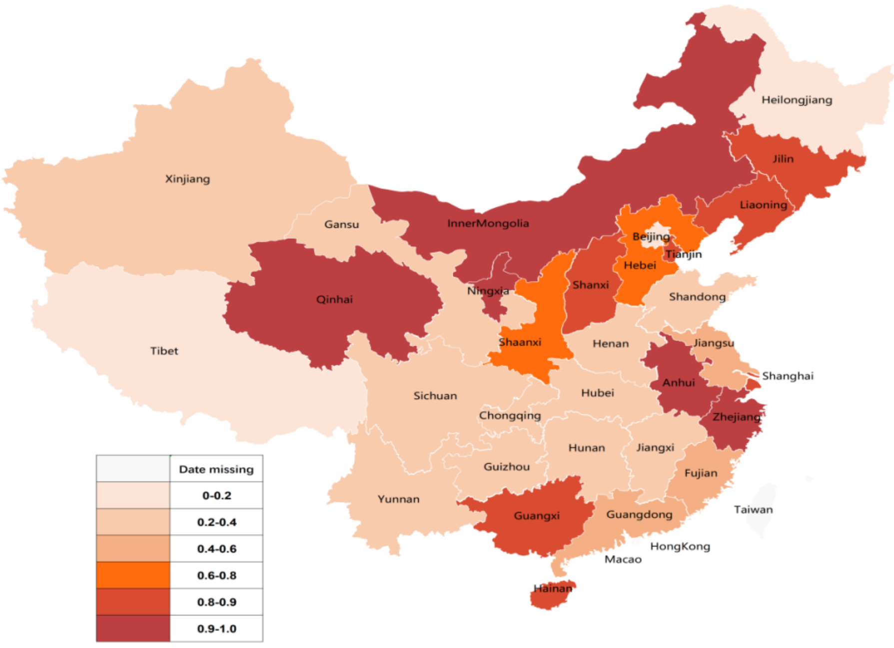

Fig. 1. Average comprehensive technical efficiency of cold chain logistics for fresh agricultural products in Shandong and China, 2019–2023

Pure Technical Efficiency Comparison of Cold Chain Logistics for Fresh Agricultural Products. As shown in Figure 2, Shandong Province has the lowest pure technical efficiency among China's eastern coastal regions, ranging from 0.4–0.6, while many provinces exceed 0.9. This low efficiency highlights inadequate resource utilization and poor management processes in Shandong. To improve, it is recommended to implement digital management, optimize transport and storage, adopt better management models, and provide technical training. The lack of technological innovation, such as temperature monitoring, intelligent warehousing, and transportation, coupled with a reliance on traditional industries, also contributes to Shandong's low efficiency. There is significant room for improvement in resource use and management.

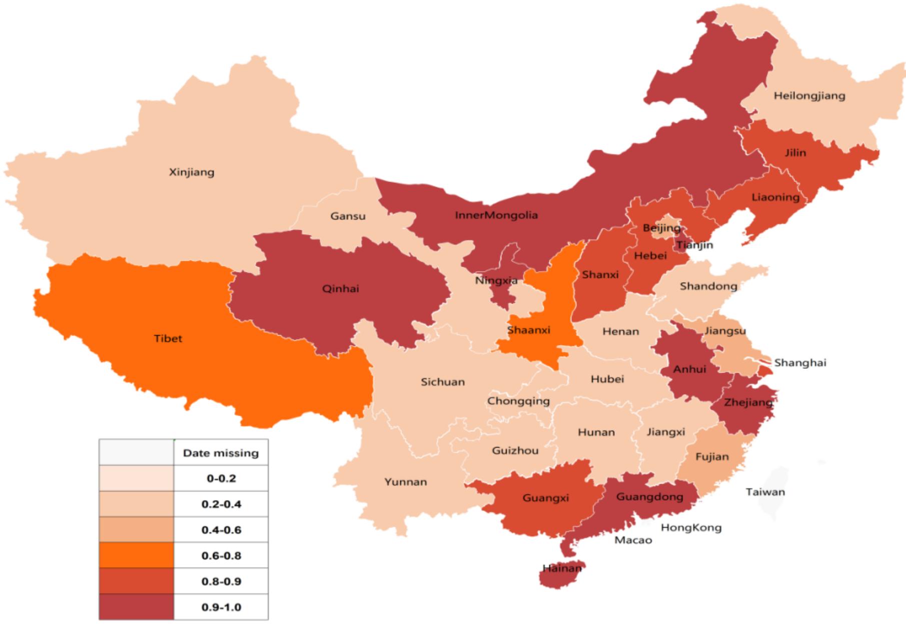

Fig. 2. Average pure technical efficiency of cold chain logistics for fresh agricultural products in Shandong and China, 2019–2023

Scale Efficiency Comparison of Cold Chain Logistics for Fresh Agricultural Products. As shown in Figure 3, Shandong Province's scale efficiency is above 0.9, similar to most provinces, indicating that its cold chain logistics for fresh agricultural products is nearing an optimal scale, with minimal room for expansion. The coordination between logistics stages is strong, but despite high scale efficiency, Shandong's comprehensive technical efficiency remains low compared to other provinces. To improve, Shandong should focus on enhancing pure technical efficiency through technological innovation and better management strategies, which would in turn boost its overall technical efficiency.

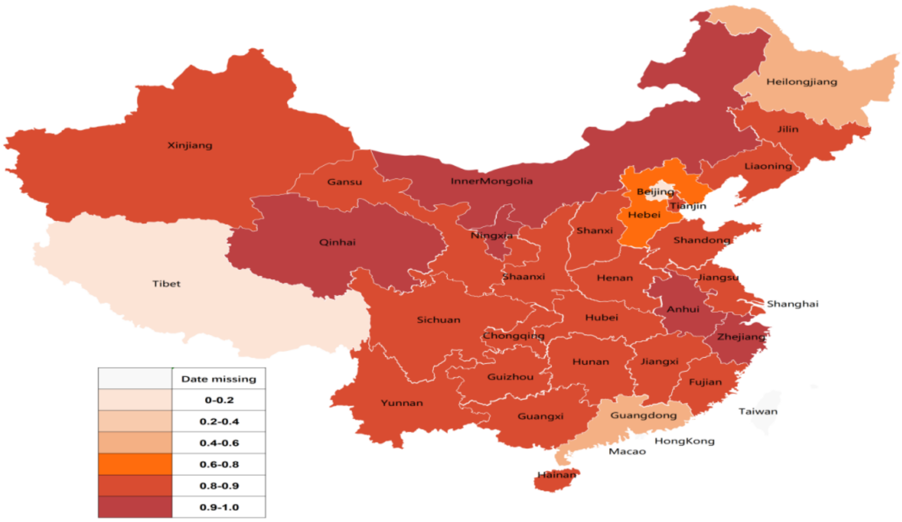

Fig. 3. Average scale efficiency of cold chain logistics for fresh agricultural products in Shandong and China, 2019–2023

3.2 Dynamic Changes in the Efficiency of Cold Chain Logistics for Fresh Agricultural Products

Based on the DEA static analysis, the Malmquist index analysis method is used to dynamically analyse the efficiency of cold chain logistics for fresh agricultural products in Shandong from 2019 to 2023. After sorting, it is shown in the figure.

Dynamic Changes in the Efficiency of Cold Chain Logistics for Fresh Agricultural Products in Shandong. Figure 4 shows that total factor productivity (TFP) in Shandong's fresh produce cold chain logistics industry initially declined but later improved. The drop from 2019 to 2020 was due to the COVID-19 pandemic, which disrupted logistics, increased costs, and lowered efficiency. The industry's lack of flexibility and emergency response mechanisms also contributed to the decline. However, TFP remained stable between 2020 and 2021 and then increased from 2021 to 2023 due to technological advances and improved scale efficiency. Shandong introduced policies like the 'Cold Chain Logistics Development Special Action Plan,' which supported infrastructure, tech innovation, and digital transformation. As market demand grew, enterprises expanded operations, optimized logistics routes, and enhanced equipment use, reducing costs and increasing competitiveness, leading to higher TFP.

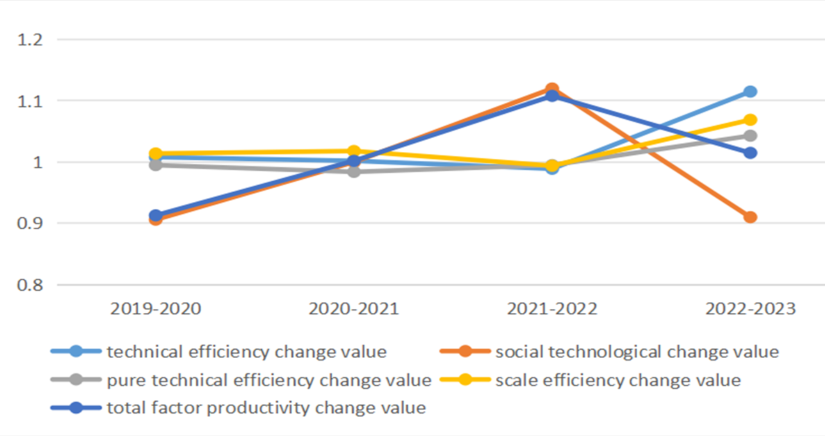

Fig. 4. Rate of change of various values of cold chain logistics for fresh agricultural products in Shandong, 2019–2023

Dynamic Changes in the Efficiency of Cold Chain Logistics for Fresh Agricultural Products Nationwide. Figure 5 shows that the total factor productivity (TFP) of China's fresh agricultural cold chain logistics initially declined, then rose, followed by another decline. From 2019 to 2021, the pandemic caused a slowdown in technological innovation and disrupted supply chains, hindering research and development. Companies prioritized survival over investing in new technologies, leading to a continued TFP decline. However, between 2021 and 2022, advancements in e-commerce, AI, and internet applications improved logistics efficiency, boosting TFP. The 2022–2023 decline in TFP is due to global supply chain fragility, semiconductor shortages, and reduced technological innovation. Companies adopted conservative strategies, slowing technological progress and reducing TFP.

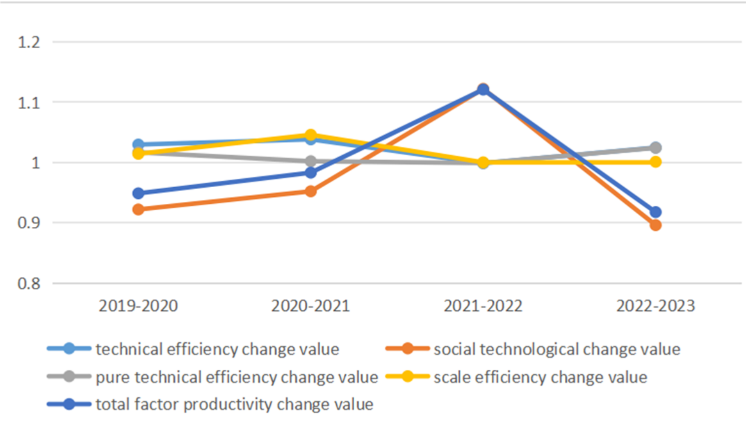

Fig. 5. Rate of change of various values of cold chain logistics for fresh agricultural products in China, 2019–2023

Comparison of the Dynamic Changes in the Efficiency of Cold Chain Logistics for Fresh Agricultural Products in Shandong and the Whole Country. During 2020–2021 and 2022–2023, Shandong's cold chain logistics for fresh agricultural products outperformed the national average in development efficiency and stability. Despite the pandemic in 2020–2021, Shandong adapted quickly by optimizing transport routes, enhancing cold storage, and expanding its cold chain fleet in response to rising demand. Its effective pandemic control measures also accelerated logistics recovery, resulting in stable development compared to other regions. In 2022–2023, Shandong introduced advanced technologies like automated warehousing and intelligent sorting, reducing costs and errors while boosting technical efficiency. Additionally, mergers and acquisitions expanded its cold chain network, lowering logistics costs and improving transport efficiency, leading to higher total factor productivity than the national average.

4 Research Conclusions and Policy Recommendations

4.1 Research COnclusions

The static analysis shows that Shandong's cold chain logistics efficiency for fresh agricultural products is below the national average, but its scale efficiency is among the best in the country. However, comprehensive technical efficiency is generally inferior to other provinces due to low pure technical efficiency and significant improvement potential. The dynamic analysis shows that Shandong's cold chain logistics efficiency is improving faster than the national average, mainly due to technological advancements. However, there is still room for further improvement in Shandong Province.

4.2 Recommendations

(1) Shandong's cold chain logistics for fresh agricultural products should maintain and expand economies of scale by leveraging its geographic advantages and optimizing resources. Upgrading facilities, equipment, and applying IoT technology will enhance efficiency and fully realize economies of scale[9].

(2) To modernize cold chain logistics, Shandong must boost technological expertise, standardize management, and promote innovation. Government funding supports research and development, and enterprises should focus on intelligent management and temperature control systems. Establishing industry standards will ensure safety, improve operations, and build a competitive cold chain system. Enhancing infrastructure and personnel training will guarantee product quality and reduce post-harvest losses[10].

(3) Government policies should encourage R&D through tax incentives, subsidies, and investment in rural infrastructure. Supporting the integration of upstream and downstream industries will create industrial clusters, boosting efficiency and competitiveness across the entire supply chain[11].

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