RESEARCH ARTICLE

Efficiency measurement and improvement path of the whole chain of agricultural product distribution based on SBM-Malmquist model

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Under the background of globalization and informatization, agricultural products circulation is a key link connecting agricultural production and consumer demand, and its efficiency directly affects food safety, freshness, and market stability. However, the circulation chain of agricultural products is long and complex, involving production, acquisition, processing, storage, transportation, wholesale, retail and other links, often facing problems such as asymmetric information, large loss, high cost, and lagging technology application, which seriously restricts the effective supply and value promotion of agricultural products. Therefore, it is of great significance to explore the strategy of improving the efficiency of the whole chain for promoting agricultural modernization and ensuring people's livelihood. This study was to analyze the operation mechanism of the whole chain of agricultural products circulation to clarify the function and efficiency bottleneck of each link in agricultural products circulation and propose systematic efficiency optimization scheme. The research used Slack-Based Measure (SBM)-Malmquist model to scientifically measure the efficiency level, technological progress, and pure technical efficiency of each link from production to retail and the dynamic change of the whole chain through precise analysis of mass data to provide solid data support for subsequent strategy formulation. The results showed that the efficiency of different circulation links varied, and technological progress and management improvement were the key driving forces to improve efficiency. The perfection of infrastructure, the intensity of market competition, the friendliness of policy environment, and the flexibility of organizational operation mode were identified as important external factors affecting circulation efficiency. These findings verified the early theoretical assumptions and provided guidance for practice. This study not only revealed the current situation and problems of the whole chain efficiency of agricultural products circulation, but also provided a theoretical framework and practical path for improving circulation efficiency, which was of great value for promoting the transformation and upgrading of agricultural industrial chain, ensuring the effective supply of agricultural products, and promoting the development of rural economy. In the future, the research results are expected to guide the formulation of relevant policies and the practice of enterprises and help to build a more efficient and sustainable agricultural product circulation system.

Keywords: SBM-Malmquist model; agricultural distribution; whole chain efficiency measurement.

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Introduction

As a link between agricultural production and consumption, the efficient operation of the whole chain of agricultural product circulation is not only crucial to guaranteeing national food security, promoting the upgrading of the agricultural industrial structure, raising the income of farmers, and meeting the diversified needs of consumers, but also has a strategic value that cannot be ignored in realizing sustainable economic and social development. Under the wave of globalization and informatization, although the circulation system of agricultural products plays a pivotal role, it is also facing a series of complex and severe challenges. There is an urgent need to carry out in-depth analysis and optimization with the help of scientific means to enhance its overall effectiveness and services to the development of modern agriculture and rural revitalization strategy [1]. As an effective transfer process of food from the origin place to the place of consumption, the efficiency of agricultural product circulation is directly related to the stability and resilience of the national food supply chain. An efficiently operated agricultural product circulation system can quickly respond to changes in market demand, flexibly adjust the supply structure, quantity and effectively suppress market fluctuations, and enhance the ability to guarantee food security. In case of sudden events and other uncertainties, especially in response to natural disasters, a strong agricultural circulation network can quickly deploy resources to ensure the continuity and reliability of food supply and build a solid line of defense for national food security [2]. The whole chain of agricultural product circulation covers several key links from production, processing, storage, transportation to sales. Its efficiency directly affects the competitiveness of the entire agricultural industry chain. Optimizing the circulation of agricultural products can guide agricultural production to standardization, scale, branding direction by improving the quality of agricultural products, rich product variety, shaping the regional characteristics of the brand, and other ways to enhance the added value of agricultural products, and promote the structure of the agricultural industry from the traditional crude to modern intensive transformation. In addition, efficient circulation can also promote the deep integration of agriculture and secondary and tertiary industries, giving rise to new forms and new models, and injecting new momentum into the upgrading of the agricultural industry [3, 4]. The efficient circulation of agricultural products can help compress intermediate links, reduce transaction costs, minimize the loss of agricultural products in the process of circulation, and bring the price of agricultural products closer to their true value, thus increasing farmers' income through the construction of a fair and transparent circulation environment, eliminating the information asymmetry, ensuring farmers receiving a reasonable return and further stimulating their production enthusiasm, and vigorously promoting the enhancement of agricultural productivity. Although the circulation of agricultural products is of great significance to economic and social development, in actual operation, there are still some bottlenecks restricting the improvement of its efficiency, which include backward infrastructures, serious information asymmetry, low degree of circulation organization, lack of perfect policy environment [5]. It is urgent to carry out in-depth analysis and optimization of its efficiency through scientific means to enhance the overall effectiveness of the circulation system of agricultural products, and to provide a strong support for the development of modern agriculture and the strategy of rural revitalization [6]. The agricultural product circulation chain encompasses production, procurement, processing, warehousing, transportation, and wholesale/retail, constituting a cohesive value chain that significantly impacts the agricultural economy and food safety. The efficiency and service quality directly impact sales and brand perception. Each link in this chain is interconnected and interdependent, collectively driving the seamless transition of agricultural goods from production to consumption. Enhancing operational efficiency across every stage is imperative for optimizing the overall efficacy of the system and fostering a sustainable agricultural sector [7, 8].

Slack-Based Measure (SBM)-Malmquist model combined Data Envelopment Analysis (DEA) and Malmquist productivity index method can dynamically and comprehensively evaluate the technical efficiency, pure technical efficiency, scale efficiency, and total factor productivity of decision-making units with considering the redundancy of inputs and the insufficiency of outputs. Through the SBM-Malmquist model, the efficiency short boards of each link of agricultural product circulation can be accurately identified to provide scientific basis for targeted improvement measures [9]. The main idea of SBM is to use mathematical planning methods to compare the performance of decision-making units under specific input and output conditions with the optimal production boundary to assess their relative efficiency, which not only considers the distance between decision-making units and the optimal production boundary, but also pays attention to the "slack", i.e., redundancy, of the input and output. The Malmquist productivity index is used to measure the change of total factor productivity (TFP) of the decision unit in different periods, which consists of technical progress (TPCH) and efficiency change (EFFCH) [10, 11]. The TPCH index reflects progress at the technological level and the extent to which the frontier of production possibilities expands without changing efficiency. EFFCH reflects the changes in the management level within the decision-making unit including pure technical efficiency change (PECH) and scale efficiency change (SECH), reflecting the improvement of the operation status of enterprises within the established production possibility boundary [12, 13].

The research on circulation efficiency of agricultural products is an important part of agricultural economics and logistics, and it is of great significance to system performance evaluation and strategy formulation. This study analyzed the efficiency of the whole chain of agricultural product circulation in China using the SBM-Malmquist model integrated with Internet of Things (IoT), big data, and e-commerce, and investigated the relationship between the factors and the mechanisms. The results of this study would provide a powerful blueprint for efficiency improvement in China's agricultural sector by integrating advanced analytical tools to enhance understanding of efficiency factors and formulate targeted strategies.

Materials and methods

Dataset

Primary dataset was obtained from Institute of Agricultural Economics, Chinese Academy of Agricultural Sciences, Beijing, China through structured interviews and surveys conducted with farmers, agribusinesses, wholesalers, retailers, and logistics providers across multiple regions in China including, but not limited to, Shandong Province, a prominent agricultural hub, Guangdong Province, known for its diverse produce, and Beijing, a major center for wholesale and retail activities from January 2020 to December 2021, which captured a robust timeframe that encapsulated seasonal variations and potential impacts of the COVID-19 pandemic on the agricultural sector [14, 15]. The dataset was meticulously compiled from various sources to ensure comprehensive and reliable insights into the agricultural product distribution chain. During the selection of samples, the representativeness of geographical distribution, scale of operation, industry format and other dimensions, and strive to achieve the breadth of analytical perspectives and the validity of the conclusions were fully considered [16]. A complete set of pre-processing procedures was strictly followed for the acquired raw data before data analysis, which included handling of missing values, outlier detection and correction, and data normalization (Figure 1). The handling of missing values used a series of scientifically sound interpolation techniques including mean and median or nearest neighbor value for continuous variables or being interpolated based on the frequency distribution or other statistical features for discrete variables, aiming to maximize the retention of the original data structure and trends to ensure the integrity of the data [17]. Outlier detection and correction used Boxplot method, Z-score criterion, and other applicable tests to identify and analyze

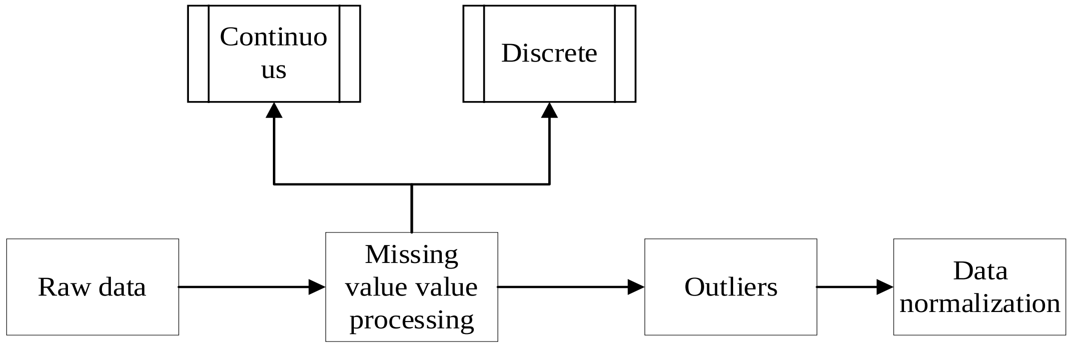

Figure 1. Flow chart of data processing.

outliers that were far from the normal data range. Once identified as outliers, the appropriate treatment strategies were adopted according to different scenarios and reasons to eliminate obvious error records or converting them reasonably to avoid the outliers misleading the results of subsequent analysis. Data normalization was to eliminate the differences in scale between different indicators and improve the accuracy and stability of the model calculation. Normalization operations for both input and output variables were implemented. Specifically, Min-Max standardization (mapping the data to the [0, 1] interval) or Z-score standardization (transforming the data into a standard normal distribution) were selected, so that the indicators of different properties and scales could be compared and analyzed under the same benchmark, which was crucial for the subsequent quantitative assessment of the efficiency of the whole chain of agricultural product circulation using the SBM-Malmquist model [18].

Input-output indicator system setting

To comprehensively and accurately reflect the efficiency of the whole chain of agricultural products circulation, a set of input-output indicator system that included production, acquisition, processing, storage, transportation, wholesale, and retail was set up according to its characteristics and was shown in Table 1.

SBM-Malmquist model construction

According to the input-output index system, the SBM-Malmquist model was designed and established, which was specialized in measuring the efficiency of the whole process of agricultural product circulation. In this model, an objective function, the minimization efficiency coefficient θ, was set up with the mathematically expression as follows:

$$\theta * Y = X$$
$$\theta \geq 0$$
$$Y \geq 0$$

where θ was the efficiency value of the decision-making unit (in this case, it represented the independent links or the whole chain of agricultural product circulation), which was the key parameter to measure the efficiency of system resource utilization. X was the input vector, which included various resource indicators invested by each link in the process of operation such as land use area, labor input, fertilizer and pesticide use intensity, acquisition costs, depreciation of processing equipment, maintenance costs of storage facilities, transportation costs, and marketing expenses. Y was the output vector, which covered the economic and social benefits generated by each link such as agricultural output, total amount of purchases, total output of processed products, total amount of products shipped out of warehouses, amount of transportation, and final sales.

Table 1. Indicator system.

Annular ring	Input indicators	Output indicators
production sector	Land use area, labor inputs, fertilizer and pesticide use intensity, seed costs, *etc*.	agricultural production
Acquisition process	Raw material acquisition costs, human resource expenditures, depreciation costs of acquisition equipment, information collection costs, *etc*.	Total acquisitions
Processing sector	Raw material acquisition costs, depreciation of processing machinery, energy consumption, labor costs, packaging material expenses, *etc*.	Total production of processed products
Storage link	Depreciation of warehouse facilities, energy consumption, staff remuneration, cost of preservatives, stock loss, *etc*.	Total actual outgoing
Transport sector	Depreciation of means of transportation, fuel consumption, labor costs, insurance costs, loading and unloading costs, *etc*.	Transportation actually accomplished
Wholesale and Retail Segments	Site rental costs, personnel salaries, marketing expenses, merchandise wastage costs, logistics costs, *etc*.	Final sales

The model sought the smallest efficiency coefficient (θ) through the optimization algorithm to ensure that, under the premise of keeping the current output level (*Y*) unchanged, the input indexes in the input vector (*X*) were compressed to the maximum extent, i.e., the resource consumption was reduced as much as possible under the condition of the same output to objectively and accurately reflect the actual operational efficiency of the decision-making unit in the whole chain of agricultural product circulation [19].

Model evaluation

Three indicators were employed in this study including the technical progress index (TPCH), the pure technical efficiency change index (PECH), and the potential relationships between infrastructure investment, market competitiveness, policy support, organizational model, and distribution efficiency. The TPCH was an important measure of the magnitude of change in total factor productivity (TFP) in a decision-making unit over two consecutive periods and was calculated as follows.

$$TPCH = (\theta_{t+1} Y_{t+1}) / (\theta_t Y_t)$$

where θ_t and θ_{t+1} were the efficiency values for two consecutive periods, respectively. Y_t and Y_{t+1} were the output vectors for these two periods. The PECH focused on the change in managerial efficiency inherent in the decision-making unit, which was derived by comparing the efficiency values of two consecutive periods and was calculated as below.

$$PECH = \theta_{t+1} / \theta_t$$

In addition, the potential relationships between infrastructure investment (I), market competitiveness (M), policy support (P), organizational model (O), and distribution efficiency (E) were expressed in the following formula [29, 30].

$$E = \beta_0 + \beta_1 I + \beta_2 M + \beta_3 P + \beta_4 O + \grave{o}$$

where β_0 to β_4 were the parameters to be estimated. $\grave{o}$ was the random error term.

Statistical analysis

SPSS version 27 (IBM, Armonk, New York, USA) was employed for statistical analysis in this study. One-way ANOVA was used to discern variations in efficiency across distinct supply chain nodes. Pearson correlation was applied to explore the strength and direction of relationships between efficiency metrics and influential determinants. The *P* value less than 0.05 was defined as a significant difference.

Results

By using the SBM-Malmquist model constructed in this study, each independent link and its overall efficiency in the whole chain of agricultural product distribution was accurately calculated. The efficiency values of each link and its whole chain were shown in Table 2. All the efficiency values fell within the range of [0, 1], and the closer the value was to 1, the more efficient the operation of the link or the whole chain was. The warehousing link showed relatively high efficiency, while the overall efficiency of the whole chain was 0.83, indicating that the whole distribution system still had a large optimization space [20].

Table 2. The efficiency values for each link and the whole chain.

Annular ring	Efficiency value
Give birth to a child	0.85
Acquire (a company)	0....
Working (of machinery)	0.88
Store in a warehouse	0.92
Haulage	0.90
Wholesale & retail	0.86
Full chain	0.83

The efficiency value was between 0 and 1, where 1 represented full efficiency, i.e., the maximum level of output was achieved with the existing resource input. The warehousing chain had the highest efficiency value of 0.92, indicating that the warehousing chain was the most effective in terms of resource utilization and output under the same input conditions. The efficiency value of the whole chain was 0.83, indicating that the whole agricultural product circulation system still had a certain efficiency improvement space and needed to be synergistically optimized for each link [21].

The technical progress indices of each link and the whole chain showed that, although most of the links had indices greater than 1, showing different degrees of technological progress, it was important to note that the technological progress of the acquisition link was relatively slow, while the technological progress index of the whole chain was 1.02, which implied that the productivity of the whole chain had been improved by a small margin in a certain period of time [22]. The technical progress index (TPCH) for each link and the whole chain was used to measure the extent of total factor productivity (TFP) growth over two consecutive time periods (Table 3). If the TPCH index was greater than 1, it indicated that the link or the whole chain had realized technological progress and productivity gains during that period [23, 24].

Table 3. Breakdown of technological progress indices for each link and the whole chain.

Annular ring	Technological progress index
Give birth to a child	1.05
Acquire (a company)	0.98
Working (of machinery)	1.02
Store in a warehouse	1.03
Haulage	1.01
Wholesale & retail	1.04
Full chain	1.02

The pure technical efficiency change index (PECH) for each link and the whole chain reflected the dynamic change in the level of management within the decision-making unit by comparing efficiency values over time. If the pure technical efficiency change index was greater than 1, the efficiency of the link or the whole chain was improved relative to the previous period, i.e., there had been a positive managerial or technical improvement. The production, warehousing, and wholesale and retail showed higher pure technical efficiency change indices, indicating that these segments had achieved efficiency gains through improved management or process optimization over the past period. The pure technical efficiency change index for the whole chain was also 1.04, indicating that, at the level of the whole agricultural product distribution system, improved management had played a positive role in overall efficiency (Table 4) [25].

Table 4. The index of change in pure technical efficiency for each link and for the whole chain.

Annular ring	Pure technical efficiency change index
Give birth to a child	1.07
Acquire (a company)	1.01
Working (of machinery)	1.03
Store in a warehouse	1.05
Haulage	1.02
Wholesale & retail	1.06
Full chain	1.04

Exploration of efficiency differences and influencing factors

The efficiency differences and their causes in the whole chain of agricultural product circulation were explored to provide empirical support for optimizing the agricultural product circulation system through the comparative analysis of the efficiency value of each link, the technical progress index, the pure technical efficiency change index, and the relevant influencing factors [26]. The efficiency value of the production segment was 0.65, indicating significant inefficiency in this segment. The index of technological progress was 0.98, indicating that technological progress contributed less to efficiency improvement. The pure technical efficiency change index was -0.07, indicating that the production segment failed to utilize resources efficiently under the existing technological conditions (Table 5). The possible reasons included inefficient land use, uneven quality of labor, and over-reliance on chemical fertilizers and pesticides. The efficiency value of the acquisition link was 0.75, which was at a medium level, and the index of technological progress and the index of change in pure technical efficiency were 1.02 and 0.01, respectively, indicating that the efficiency of this link was relatively stable. Although there was slight technological progress, the change in pure technical efficiency was not large. The room for improvement mainly lies in the aspects of acquisition cost control and information collection efficiency. The efficiency values of processing, storage, and transportation were all at 0.87 and above, and the technical progress indexes were 1.05, 1.03, and 1.06 respectively. The pure technical efficiency change indexes were all positive, showing that the efficiency of these three links was high and continued to progress, which reflected the significant improvement of China's agricultural product distribution infrastructure and technology application in recent years [27]. The production segment was relatively weak in terms of efficiency performance. The results showed that not only the efficiency value was low, but also the pure technical efficiency change index was negative, indicating that its internal management efficiency needed to be improved without considering technological progress. Acquisition, processing, warehousing, and transportation had relatively good efficiency performance, especially in terms of technological progress, which had a positive impact on efficiency improvement. The efficiency value of the

Table 5. Efficiency values, technical progress index, and pure technical efficiency change index for each segment of agricultural product distribution.

Annular ring	Efficiency value	Technological progress index	Pure technical efficiency change index
Give birth to a child	0.65	0.98	-0.07
Acquire (a company)	0.75	1.02	0.01
Working (of machinery)	0.87	1.05	0.04
Store in a warehouse	0.90	1.03	0.02
Haulage	0.88	1.06	0.025
Wholesalers	0.78	1.01	-0.03
Sell individually or in small quantities	0.75	0.99	-0.05

Table 6. Advanced association rule analysis.

Rule ID	Left Handset (LHS)	Right Handsets (RHS)	Support (%)	Confidence	Lift
R1	Excellent infrastructure	High circulation efficiency	60	0.80	1.5
R2	Less competitive market environment	High circulation efficiency	45	0.75	1.2
R3	Strong policy support	High circulation efficiency	70	0.90	2.0
R4	Advanced organizational models	High circulation efficiency	55	0.85	1.7

Notes: Rule ID: unique identifiers for each rule. Left handset (LHS): the conditions of the factors that affected circulation efficiency. Right handset (RHS): the possible outcomes based on the given conditions (circulation efficiency was high). Support (%): the percentage of the total sample that satisfied the rule. Confidence: the probability of a right hand event occurring when the left hand condition held. Lift: the strength of the association between two variables, which was greater than 1 indicating that there was a positive association between the two variables. The larger the value, the stronger the association.

wholesale and retail segment was lower than that of the warehousing and transportation segments, while the index of purely technical efficiency change was also negative, indicating that there was room for improvement in management efficiency and/or technological progress in these two segments.

Correlation analysis

The SBM-Malmquist model was mainly used to measure and decompose efficiency changes. However, when exploring the key factors affecting efficiency, it usually combined multivariate statistical analysis such as regression analysis, principal component analysis, *etc*. to determine the correlation between these factors and efficiency values. The results showed that there was a significant positive correlation between infrastructure conditions and the efficiency of agricultural product circulation, which meant that, with the improvement of infrastructure, such as the quality of warehousing facilities, the efficiency of transportation network, and the degree of application of information technology, *etc*., the efficiency of agricultural product circulation demonstrated a synchronous increase. The correlation coefficient was 0.85, indicating that this correlation was strong and very significant ($P < 0.01$). The correlation between the degree of competition in the market environment and the efficiency of agricultural distribution, however, showed a negative correlation with a correlation coefficient of -0.72, which implied that the efficiency of agricultural product distribution was relatively higher in less competitive market environments ($P < 0.05$). This might be because increased market competition might cause enterprises to sacrifice a certain degree of circulation efficiency to capture market share. The strength of support from the policy environment showed a strong positive correlation with the efficiency of agricultural product distribution with a correlation coefficient as high as 0.90 ($P < 0.01$) [28] (Table 6). Overall, the correlation analysis revealed that improving infrastructure, optimizing the policy environment, and organizational model were the key factors in enhancing the efficiency of agricultural product distribution, while moderately controlling the intensity of market competition was also conducive to the improvement of distribution efficiency. These findings provided policy makers and industry participants with a clear direction for improvement and a basis for decision-making. In practical application, corresponding strategies could be formulated according to specific situations such as increasing investment in infrastructure, advocating and guiding distribution enterprises to adopt more advanced organizational models, and implementing policies conducive to the improvement of distribution efficiency. It was also necessary to further study the complex dynamic relationship between market competition and circulation efficiency to seek the optimal balance between competition and efficiency.

Discussion

Theoretical construction of enhancement path

Based on the results of measuring the efficiency of the whole chain of agricultural product circulation and the in-depth investigation of its influencing factors, a systematic theoretical framework for improving the efficiency of the whole chain of agricultural product circulation was constructed by combining modern supply chain management and logistics optimization theories. From the infrastructure level, this study advocated increasing investment, upgrading the existing storage and transportation facilities, and actively introducing and popularizing information technology to build a smart logistics system, realizing real-time sharing of circulation information and full traceability, to reduce the circulation cost and improve the circulation speed and accuracy. Through the reform of the market access mechanism and the maintenance of a fair-trading environment, the market environment would be optimized, and the moderate competition was advocated, which prompted the circulation of the main body to take the initiative to improve the quality of service and operational efficiency. Furthermore, strengthening the role of policy guidance, formulating and implementing targeted financial subsidies and tax incentives would encourage the main circulation of technological transformation, equipment renewal, and model innovation. Advocating and promoting the change of organization mode, encouraging the scale, specialization, synergistic circulation mode, realizing the seamless connection between the upstream and downstream of the industrial chain would maximize the circulation efficiency.

Specific measures to enhance the path

Path enhancement measures mainly included technological innovation, process reengineering, policy guidance, and market mechanism optimization (Figure 2). In the process of promoting scientific and technological innovation in the circulation of agricultural products, the applications of cutting-edge technological means such as the Internet of Things, big data analysis, cloud computing, and so on were emphasized to realize the highly intelligent and transparent operation of agricultural products circulation system. By installing intelligent sensing equipment and integrating information processing systems, the entire circulation status of agricultural products from field to table were monitored and tracked in real time to ensure the accuracy and immediacy of information transmission, thus significantly reducing the circulation cost, accelerating the speed of circulation, and enhancing the accuracy of circulation. In addition, actively responding to the development trend of green logistics, scientific research institutions, and enterprises were encouraged to research, develop, and widely apply environmentally friendly packaging materials and low-carbon transportation equipment such as biodegradable packaging, new energy vehicles, *etc*. to effectively reduce environmental pollution and realize the green and sustainable development of the circulation of agricultural products.

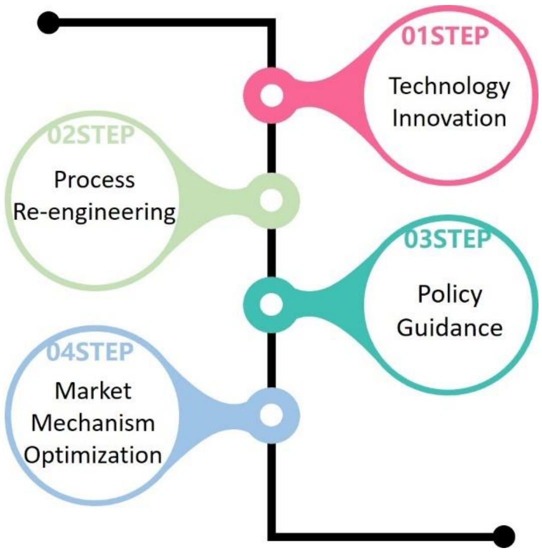

Figure 2. Elevation path measures.

In view of the current situation of the circulation chain of agricultural products, a comprehensive and detailed sorting and process optimization should be carried out, aiming at removing the wheat from the chaff and constructing a leaner and more agile circulation process. In the production chain, it should vigorously promote the order agriculture model, relied on big data to predict consumer demand, guide agricultural production to follow the market demand, implement production according to demand, supply according to demand to avoid invalid inventory and waste of resources due to mismatch between supply and demand. In the distribution chain, the integration of scattered warehousing and transportation resources, the promotion of the implementation of common distribution, centralized purchasing, and other strategies should be considered through rational scheduling and efficient cooperation to significantly reduce the cost of the distribution chain and energy consumption to enhance the overall effectiveness of the distribution. Governments play a crucial role in the process of improving the efficiency of agricultural product distribution. It should actively formulate and implement a series of policies and initiatives conducive to the improvement of circulation efficiency including the provision of substantial financial subsidies and tax incentives for technological research and development, facility construction, energy conservation, and emission reduction to motivate enterprises to boldly introduce and independently research and development of advanced and applicable technologies and management modes. Meanwhile, it should continuously improve and strengthen the standard system for the circulation of agricultural products through the rigid constraints and flexible guidance of laws, regulations, and related policies to encourage the main body of the circulation in compliance with the norms based on consciously improving their own operational efficiency and level of service. The society commits to build an open, transparent, competitive, and orderly market environment for the circulation of agricultural products to incentivize all types of market players to take the initiative to improve their service quality and operational efficiency through a fair competition mechanism. Therefore, the geographical barriers should be broken down, the market rules should be strengthened, and all kinds of circulation subjects to actively participate in the market competition through the survival of the fittest to give birth to a number of efficient operations, quality service of agricultural products circulation enterprises should be encouraged.

Conclusion

This study constructed a set of efficiency measurement models covering production, acquisition, processing, warehousing, transportation, wholesaling, and retailing through in-depth analysis of the whole chain of agricultural product distribution and empirically analyzed them in combination with the SBM-Malmquist model and derived the efficiency values, technical progress indexes, and purely technical efficiency change indexes for each link and the whole chain. The results showed that, although certain links such as warehousing and processing had demonstrated higher efficiency and significant technological progress, overall, there was still much room for improvement in the efficiency of the whole chain of agricultural product distribution, especially in the production, acquisition, and wholesale and retail links. Through an in-depth investigation of efficiency differences and their influencing factors, the significant impact of key factors such as infrastructure, market competition, policy support, and organizational model optimization on the efficiency of agricultural product distribution were clarified. The improvement of infrastructure and the application of information technology could significantly improve the distribution efficiency, while a suitable market competition environment was conducive to improve the operational efficiency of the distribution entities while maintaining high quality services. Policy support played a positive role in promoting technological innovation, equipment updating, and model innovation. The changes in the organizational model such as order farming and integrated distribution model helped to realize the efficient synergies between the upstream and downstream of the industrial chain. Based on the theoretical construction of the enhancement path, four specific measures including technological innovation, process reengineering, policy guidance, and optimization of market mechanisms were put forward. Through the applications of advanced technologies such as the Internet of Things, big data, cloud computing, as well as the implementation of lean and agile circulation processes, it was possible to effectively reduce the cost of circulation and improve the efficiency and responsiveness of circulation. The policy level of financial subsidies, tax and other incentives, as well as the construction and improvement of the circulation standard system to promote the transformation and upgrade of the circulation of the main body had an indispensable role. By building a fair, transparent, and competitive market environment and creating a national trading platform for agricultural products, the allocation of resources could be further optimized to ensure the smooth and efficient operation of the whole chain of agricultural product circulation.

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