Economics & Business Management
ISSN Print: 3079-5214
ISSN Online: 3079-5222
https://doi.org/10.63313/EBM.9131

Measurement of the Resilience of Agricultural Product Supply Chains under Digital Technology

Xin Zhang. Lina Fang*
College of Business Administration, University of Science and Technology Liaoning, Anshan, China
Email: asfanglina@163.com

How to cite this paper: Zhang, X., & Fang, L. N. (2025). Measurement of the resilience of agricultural product supply chains under digital technology. *Economics & Business Management*, 4(1), 83-95. ISSN Print: 3079-5214; ISSN Online: 3079-5222.
https://doi.org/10.63313/EBM.9131
Published: 2025-12-19

Abstract

In the context of intensified global competition and increased uncertainty, enhancing the resilience of the agricultural product supply chain has become a key to ensuring the stability of the supply chain. This paper constructs an evaluation index system for the resilience of the agricultural product supply chain from five dimensions: resistance capability, adaptability, response capability, recovery capability, and learning capability. Taking six representative agricultural enterprises, namely X Company, B Company, M Company, H Company, W Company and Y Company, as the research objects, the entropy weight - TOPSIS method was used to measure and rank the resilience of the agricultural product supply chain from both individual indicators and comprehensive indicators, and to conduct an analysis. The research results show that this method can effectively assess the resilience of the agricultural product supply chain. Based on the research results, suggestions are proposed to achieve a comprehensive improvement of the resilience of the agricultural product supply chain in the digital technology context by increasing investment in digital technology, emphasizing talent cultivation and team building, and strengthening cooperation and collaboration among supply chain partners.

Keywords

Digital technology; Agricultural product supply chain; Supply chain resilience; Entropy weight - TOPSIS method

1. Introduction

Agricultural development holds a significant position in China's economy. Agricultural products are essential commodities for ensuring people's livelihood. The stability and resilience of the agricultural product supply chain play a crucial role in safeguarding national food security, promoting sustainable agricultural development, and improving people's living standards. In traditional agricultural supply chains, as the supply chain involves multiple links such as production, processing, transportation, and sales, and is influenced by various factors such as natural conditions, market fluctuations, and policy adjustments, the supply chain exhibits high vulnerability and the information between upstream and downstream cannot be transmitted promptly and effectively. As a result, information sharing cannot be achieved, and the herd effect caused by the amplification and delay of information leads to significant fluctuations in the upstream of the agricultural product supply chain affecting the downstream. For example, from consumers to farmers, the demand information gradually amplifies during the transmission process, resulting in inventory accumulation and loss, which causes the deterioration and waste of agricultural products. To reduce costs, merchants have to raise prices to compensate for the losses, but consumers may not accept this consequence, affecting the quality of agricultural products while also causing economic losses to the various entities in the agricultural product supply chain. Under various emergencies, the resilience of the agricultural product supply chain faces severe challenges. Establishing a good resilience of the agricultural product supply chain can effectively resist the impact of emergencies. Therefore, how to effectively measure and enhance the resilience of the agricultural product supply chain is a current hot issue in the academic community.

The 2023 Central Document No. 1 proposed to accelerate the application of agricultural big data and promote the development of smart agriculture. By applying digital technologies such as the Internet of Things, big data, artificial intelligence, and blockchain, it is possible to digitally transform agricultural production, operation, management, and services, providing new possibilities for improving the transparency, efficiency, and resilience of the supply chain. Digital technologies can monitor all links of the supply chain in real time, respond quickly to market changes, optimize resource allocation, reduce information asymmetry, and thereby enhance the efficiency of supply chain operation while strengthening its ability to respond to emergencies. However, in the current digital context, the application of digital technologies in the agricultural supply chain is not deep enough. Therefore, the focus of this research is on the measurement of the resilience of the agricultural product supply chain in the digital technology context, with the core enterprises of the agricultural product supply chain as the research object, and from the overall perspective of digital technology to examine the resilience of the agricultural product supply chain.

The field of supply chain is one of the research focuses for the application of digital technologies. The integration of digital technologies and supply chain management is accelerating, which is speeding up the efficient and stable development of the supply chain [1]. Digital technologies can promote the stability of the supply chain by achieving the coordination and matching of agricultural product supply and demand or by reengineering the process of the agricultural product supply chain [2]. Specifically, the Internet of Things technology provides a new operational model for enterprises in logistics supply chain management, by obtaining real-time location information of goods to achieve visualization of the entire supply chain [3]. Digital finance integrates data resources from upstream and downstream of the industry chain, breaks the barriers between the flow of funds and information flow, builds a supply chain financing platform, effectively avoids risks, and realizes supply chain collaboration and information sharing [4]. Blockchain technology enables data interconnection and communication among different links of the agricultural product supply chain, and allows the entire product process to be comprehensively inspected and understood. It breaks the "information island" predicament of the supply chain at the fundamental level and realizes full-process and comprehensive traceability of the supply chain [5]. The rapid development of digital technologies enhances the visibility, traceability, security and adaptability of the supply chain [6], and these characteristics are very important for the resilience of the supply chain [7].

The concept of resilience originated from physics and engineering, used to describe the characteristic of materials and substances that are less likely to break or crack during deformation. With the development of time, this concept has gradually been applied to various disciplines and social fields. Aura et al. (2002) introduced the concept of resilience into economics and defined it as the ability to resist external shocks [8]. Regarding the assessment of supply chain resilience, the academic community has presented diverse viewpoints and a lively debate on the classification of measurement dimensions, and a complete unification has not yet been achieved. Timothy et al. (2010) based on the early research viewpoints, proposed to assess supply chain resilience using vulnerability and capability, believing that supply chain resilience is the ability to withstand sudden changes, adaptability, and growth ability [9]. Hohenstein et al. (2015) believe that supply chain resilience refers to the predictive ability of the supply chain when emergencies occur, the rapid response and recovery to potential disruptions, and the restoration to the original state and growth [10]. Md and Mohammed (2016) divided the measurement dimensions of supply chain resilience into preparedness ability, response ability, and recovery ability [11]. With the deepening of research, the measurement dimensions of supply chain resilience have also increased. Abubakar et al. (2017) divided supply chain resilience into five categories: predictive ability, adaptive ability, response ability, recovery ability, and learning ability [12]. Fan and Lu (2020) replaced the response ability with the reaction ability, and constructed a supply chain resilience evaluation index system from five dimensions: predictive ability, adaptive ability, reaction ability, recovery ability, and learning ability [13]. Yan and Liu (2024) constructed an evaluation index system for the resilience of urban life support supply chain under sudden public health events, consisting of five dimensions: early warning ability, response ability, adaptive ability, recovery ability, and innovation ability, aiming to cope with supply chain emergencies [14].

In conclusion, digital technology provides a new approach for enhancing the resilience of the agricultural product supply chain. Scientifically and reasonably measuring the resilience of the supply chain is the prerequisite for optimizing supply chain management strategies and guiding practical applications. This paper intends to adopt the entropy weight-TOPSIS method as the research method. This method combines the objectivity of determining indicator weights by the entropy weight method and the scientificity of comprehensive evaluation and ranking by the TOPSIS method, and can more comprehensively reflect the performance differences of the agricultural product supply chain in each dimension of resilience. Taking the relevant data of six representative agricultural product enterprises that all apply digital technology, namely X Company, B Company, M Company, H Company, W Company and Y Company, as samples, the supply chain resilience of these enterprises was measured, ranked and analyzed using the entropy weight - TOPSIS method.

2. Selection of Evaluation Indicators for the Resilience of Agricultural Product Supply Chains under Digital Technology

Constructing an evaluation index system requires considering the principles of sytematicness, availability, scientificity and dynamics. Drawing on the viewpoint of Wang and Si (2024), they constructed an evaluation index system for industrial chain resilience from three dimensions: resistance, adaptability and recovery, and explored the influence mechanism of digitalization on industrial chain resilience. Digital technology promotes the in-depth development of digitalization[15]. Considering the characteristics of digital technology and the connotation of supply chain resilience, this paper divides agricultural product supply chain resilience into five dimensions, namely resistance capability, adaptability, response capability, recovery capability, and learning capability (see Table 1). Specifically:

(1) Resistance capability. Resistance capability refers to the ability of a supply chain to maintain normal operation and stability when facing external environmental shocks or disturbances. Its strength is mainly reflected in the degree of risk resistance. The number of employees and fixed assets of an enterprise reflect the human and material resources of the enterprise. The more abundant the resources, the stronger the enterprise's ability to resist risk shocks. A lower debt-to-equity ratio usually indicates a more stable financial structure, enabling the enterprise to better withstand external shocks and uncertain risks. The equity multiplier reflects the size of the enterprise's financial leverage. The smaller this ratio is, the greater the proportion of the owner's capital in the total assets of the enterprise, the lower the debt level of the enterprise, and the higher the protection of the creditor's equity. Therefore, this paper selects the number of employees, fixed assets, debt-to-equity ratio, and equity multiplier as the evaluation indicators for the resistance capability of the agricultural product supply chain.

(2) Adaptability. Adaptability refers to the ability of the supply chain to flexibly adjust and optimize itself in response to environmental changes, in order to cope with and adapt to these changes. This is a fundamental element of supply chain resilience. The growth rate of operating income is an important indicator for measuring the

business conditions and development potential of an enterprise. When market demand changes, enterprises need to promptly adjust production plans and optimize inventory, etc., in order to meet the new market demands and maintain or increase the growth rate of operating income. The inventory turnover days are a comprehensive indicator for measuring the enterprise's procurement and sales aspects, and it reflects the enterprise's coordination ability. Therefore, this paper selects the growth rate of operating income and the inventory turnover days as two indicators for evaluating the adaptability of the agricultural product supply chain.

(3) Response capability. Response capability emphasizes that when risks occur, the supply chain can promptly perceive and identify changes in the environment, and quickly respond to risks, reducing or eliminating the impact of external shocks. Market capability enables enterprises to respond quickly and adjust their market strategies when facing market changes and competitive challenges, maintaining a leading position in the market. Therefore, this paper selects three indicators - market transaction volume, investment amount, and market size - as evaluation indicators for the response capability of the agricultural product supply chain.

(4) Recovery capability. Recovery capability refers to the ability of the supply chain to return to its original or better state after being subjected to external shocks. When encountering major shocks or market fluctuations, if enterprises can promptly take response measures to resume production and supply, they can maintain normal financial conditions. If enterprises can recover stability faster than their competitors, they can thereby enhance their market competitiveness. Financial strength can promote the recovery speed of enterprises, and the recovery capability of enterprises can guarantee the financial situation. Therefore, this paper selects four indicators - inventory turnover rate, return on net assets, net profit margin, and net profit - as evaluation indicators for the recovery capability of the agricultural product supply chain.

(5) Learning capability. Learning capability refers to the ability of an enterprise to actively summarize and reflect after being impacted and returning to normal. It involves accumulating experience from the influencing events and completing self-learning. Learning ability is an important factor for maintaining the sustainable development of the supply chain. Learning ability focuses on innovation. The enterprise's R&D expenditure, the proportion of higher education personnel, and the proportion of R&D personnel are all important influencing factors of innovation ability. Therefore, this paper selects four indicators - asset turnover rate, R&D expenditure, the proportion of R&D personnel, and the proportion of higher education personnel - as the evaluation indicators for the learning ability of the agricultural product supply chain.

Table 1. Evaluation Index System for the Resilience of Agricultural Product Supply Chain .

Target layer	Criterion Layer	Evaluation Index Layer	Indicator Attrib ute

Agricultural Product Supply Chain Resilience	Resistance Capability	Number of Employees	Positive
		Fixed Assets	Positive
		Debt-to-Asset Ratio	Negative
		Equity Multiplier	Negative
	Adaptability	Revenue Growth Rate	Positive
		Inventory Turnover Days	Negative
	Response Capability	Market Transaction Volume	Positive
		Investment Amount	Negative
		Market Size	Positive
	Recovery Capability	Inventory Turnover Rate	Positive
		Return on Net Assets	Positive
		Net Profit Margin	Positive
		Net Profit	Positive
	Learning Capability	Asset Turnover Rate	Positive
		Research and Development Expenditure	Positive
		Ratio of R&D Personnel	Positive
		Ratio of Higher Education Personnel	Positive

3. Entropy Weight - TOPSIS Model Construction

This paper uses the entropy weight - TOPSIS method to evaluate the supply chain resilience capabilities of six agricultural product enterprises. Firstly, the weights of each indicator are determined by the entropy weight method, and then the evaluation objects are ranked using the TOPSIS method. The specific steps are as follows:

① Construct the original evaluation matrix. Suppose there are m evaluation objects and n evaluation indicators. Construct the original matrix R_x, where X_{ij} represents the value of the jth evaluation indicator for the ith evaluation object.

$$R_x = (X_{ij})_{m*n} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (1)$$

② Construct a standardized matrix. In the indicator system, there are usually positive indicators and negative indicators. Standardizing the data can eliminate the influence of the unit on data analysis and make the indicators comparable. To ensure the validity of the values, 0.0001 is added after each value to make each data a valid value.

If it is a positive indicator:

$$\boldsymbol{Y_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} + 0.0001} \quad (2)$$

If it is a negative indicator:

$$Y_{ij}=\frac{\max(X_j)-X_{ij}}{\max(X_j)-\min(X_j)}+0.0001 \tag{3}$$

The resulting standardized matrix is:

$$R_y=(Y_{ij})_{m*n}=\begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{m1} & Y_{m2} & \cdots & Y_{mn} \end{bmatrix} \tag{4}$$

③ Calculate the weights of each indicator.

Calculate the proportion of each value to the total sum of the column:

$$P_{ij}=\frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{5}$$

Calculate the entropy value:

$$e_j=\frac{-1}{\ln(n)}\sum_{i=1}^{n} P_{ij}lnP_{ij} \tag{6}$$

Calculate the differentiation coefficient:

$$g_j=1-e_j \tag{7}$$

Calculate the weight of indicators:

$$w_j=\frac{g_j}{\sum_{j=1}^{m} g_j} \tag{8}$$

④ Construct a standardized matrix. Normalize the data in $\mathbf{R_x}$ using the square sum normalization method:

$$R_k=K_{ij}=\frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} {X_{ij}}^2}} \tag{9}$$

⑤ Construct a weighted normalization matrix. Multiply the normalized matrix $\mathbf{R_k}$ by the weight $\mathbf{w_j}$:

$$R_v=V_{ij}=K_{ij}*w_j \tag{10}$$

⑥ Determine the positive and negative ideal solutions. The positive ideal solution is $\mathbf{V^+}$, and the negative ideal solution is $\mathbf{V^-}$:

$$V_j^+=\{(max_jV_{ij}|j\in \text{Positive indicators}), (min_jV_{ij}|j\in \text{Negative indicator})\} \tag{11}$$

$$V_j^-=\{(min_jV_{ij}|j\in \text{Positive indicators}), (max_jV_{ij}|j\in \text{Negative indicator})\} \tag{12}$$

⑦ Calculate the Euclidean distance. The Euclidean distance of the positive ideal solution is $\mathbf{D}^{+}$, and the Euclidean distance of the negative ideal solution is $\mathbf{D}^{-}$:

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2} \tag{13}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2} \tag{14}$$

⑧ Calculate the relative fit degree $\mathbf{C_i}$. The larger the relative fit degree is, the stronger the supply chain resilience of the evaluated object is, and the higher the ranking will be.

$$C_i = \frac{D_i^-}{D_i^+ + D_j^-} \tag{15}$$

4. Empirical analysis

4.1. Data Source

This paper takes agricultural enterprises that have adopted digital technologies as the research subjects, and selects six representative agricultural enterprises, namely X Company, B Company, M Company, H Company, W Company and Y Company, as the evaluation objects. A resilience evaluation system for agricultural product supply chains under digital technology is constructed. The data mainly come from the financial statements of each enterprise in 2023 and the Wind financial terminal.

4.2. Individual Indicator Evaluation

This paper employs the entropy weight - TOPSIS method to assess the resilience of the agricultural product supply chain under digital support. To gain a deeper understanding of the impact of each key factor on the overall resilience of the supply chain, a separate index analysis was conducted for each of the five dimensions of resilience measurement selected- resistance capability, adaptability, response capability, recovery capability, and learning capability, where C_i represents the relative fit degree. Please refer to Table 2 for details.

In terms of resistance capabilities, it can be seen that the indicator weight of the debt-to-asset ratio is the largest among the four indicators, indicating that the debt-to-asset ratio is relatively important in terms of resilience. The debt-to-asset ratio reflects the proportion of a company's total assets that are funded through borrowing. A lower debt-to-asset ratio usually means that the company's financial structure is more stable and can better withstand external shocks and uncertain risks. According to Table 2, B Company ranks first in terms of resilience. The grain output of B Company has remained above 40 billion jin for 13 consecutive years, and the contribution rate of agricultural technological progress is as high as 77.07%, indicating that in the context of digital technology, B Company 's resilience in the face of emergencies is superior to other enterprises.

In terms of adaptability, through analysis, it can be seen that the indicator weight of the revenue growth rate is the largest among the two indicators, indicating that the revenue growth rate is relatively important in terms of adaptability. A higher revenue growth rate means that the enterprise has more cash flow, which can provide more financial resources for the enterprise to cope with uncertainties. According to Table 2, Y Company ranks first in terms of adaptability, indicating that Y Company has a better adaptability in dealing with emergencies than other enterprises.

In terms of response capability, through analysis, it can be seen that the indicator weight for the size of the market is the largest among the three indicators, indicating that the size of the market is relatively important in response capability. A larger market size usually means that the enterprise has more financial resources, which enables the enterprise to invest in advanced technologies and equipment, improving production efficiency and flexibility. According to Table 2, B Company still ranks first in response capability, indicating that B Company's response ability in the face of emergencies is superior to that of other enterprises.

In terms of recovery capability, through analysis, it can be seen that the indicator weight of the net profit margin from sales is the largest among the four indicators, indicating that the net profit margin from sales is relatively important in the aspect of recovery ability. The net profit margin from sales is a key indicator for measuring a company's profitability. Enterprises with high net profit margins usually have stronger financial reserve capabilities. These funds can be used as emergency funds to provide necessary financial support when the supply chain is impacted, helping the enterprise to resume normal operations more quickly. According to Table 2, Y Company ranks first in terms of recovery ability, indicating that Y Company has a better recovery ability in the face of emergencies compared to other enterprises.

In terms of learning ability, through analysis, it can be seen that the indicator weight of the proportion of R&D personnel is the largest among the four indicators, indicating that the proportion of R&D personnel is relatively important in learning capability. The proportion of R&D personnel is an important indicator for measuring an enterprise's innovation ability, and it can enhance the learning ability of the supply chain resilience through multiple aspects such as technological innovation, knowledge management, process optimization, risk management, and external cooperation. According to Table 2, H Company ranks first in recovery ability, indicating that H Company has a better learning ability in responding to emergencies compared to other enterprises.

The results of the individual indicators show that the application of digital technology can significantly enhance the resilience of multiple dimensions of the agricultural product supply chain. Most of the indicators selected in this article are of the outcome type, which indirectly indicates the improvement of supply chain resilience. In a complex and ever-changing environment, maintaining the normal operation and profitability of an enterprise is not an easy task. This requires enterprises to have high flexibility and adaptability to respond quickly to market changes and resist potential risks. Adhering to the trend of the times and actively embracing digital technology has become the consensus of many enterprises. Although most enterprises have already applied digital technology, the differences in the breadth and depth of its application have led to varying performances in each dimension of supply chain resilience. Therefore, for the agricultural product supply chain, it is necessary to actively apply digital technology and continuously explore its application potential in each link of the supply chain. At the same time, enterprises should also formulate scientific and reasonable digital strategies based on their own actual situations to ensure that the breadth and depth of digital technology application can truly promote the comprehensive improvement of supply chain resilience.

Table 2. Evaluation results of individual indicators for the resilience of the agricultural product supply chain.

Evaluation Object	Resistance Capability		Adaptability		Response Capability		Recovery Capability		Learning Capability	
	C_i	Sort	C_i	Sort	C_i	Sort	C_i	Sort	C_i	Sort
X Company	0.330	4	0.261	5	0.369	6	0.428	4	0.418	3
B Company	0.615	1	0.563	2	0.680	1	0.623	2	0.353	4
M Company	0.492	2	0.405	4	0.389	5	0.158	6	0.176	6
H Company	0.322	6	0.430	3	0.473	4	0.591	3	0.576	1
W Company	0.324	5	0.228	6	0.520	3	0.186	5	0.318	5
Y Company	0.465	3	0.650	1	0.569	2	0.797	1	0.527	2

4.3. Comprehensive Indicator Evaluation

A comprehensive index evaluation was conducted on the supply chain resilience of 6 agricultural product enterprises. The resilience measurement results are shown in Table 3. It can be seen that the relative fit degree C_i of Y Company is the highest, reaching 0.565, ranking first. This indicates that the supply chain resilience of Y Company is the strongest. The second-ranked B Company has a relative fit degree C_i of 0.537, which is not much different from the first place. The relative fit degrees of B Company, X Company, M Company and W Company gradually decrease, being 0.496, 0.382, 0.348, and 0.326 respectively. The supply chain resilience of Y Company, which is the strongest, actively responded to the national call, set up smart equipment and big data laboratories, and utilized Internet of Things monitoring and cloud processing technologies to achieve intelligent management and control of the entire process of poultry and livestock breeding, improving the efficiency of livestock breeding while also enhancing the quality and safety of agricultural products, and promoting the improvement of the supply chain resilience of agricultural products. The supply chain resilience of W Company is relatively the weakest among the 6 agricultural enterprises. Therefore, in the process of digital transformation, W Company needs to take a series of targeted measures to make up for the existing deficiencies and comprehensively enhance the supply chain resilience.

Table 3. Evaluation results of the comprehensive index for the resilience of the agricultural product supply chain.

Evaluation Object	C_i	Sort
X Company	0.382	4
B Company	0.537	2
M Company	0.348	5
H Company	0.496	3
W Company	0.326	6
Y Company	0.565	1

5. Conclusions and Recommendations

This paper uses the entropy weight - TOPSIS method to measure and analyze the supply chain resilience of six representative agricultural enterprises, namely X Company, B Company, M Company, H Company, W Company and Y Company, from five dimensions: resistance capability, adaptability, response capability, recovery capability, and learning capability. The research results show that digital technology has played an important role in enhancing the resilience of the agricultural product supply chain, and also reveals the differences and advantages and disadvantages among different enterprises in each resilience measurement indicator.

Overall, these six enterprises have demonstrated certain achievements in the application of digital technologies. The application of digital technologies enables enterprises to respond to market changes more quickly and precisely control the operation of each link in the supply chain, thereby enhancing the resilience of the supply chain. However, the performance of different enterprises in various resilience measurement indicators varies. For instance, some enterprises excel in resistance and recovery capabilities, but still need to improve in adaptability and learning capabilities; while others may have a stronger advantage in adaptability and learning capabilities, but are slightly lacking in resistance and recovery capabilities. Therefore, in the process of enhancing the resilience of the agricultural product supply chain, differentiated strategies and measures need to be formulated based on the actual situations of different enterprises to achieve a comprehensive improvement in the resilience of the supply chain.

Based on the above conclusions, this paper believes that the resilience of the agricultural product supply chain can be enhanced in the following aspects: First, increase investment in digital technology to promote the digitalization of the supply chain; second, focus on talent cultivation and team building to improve the digital literacy and professional skills of employees; third, strengthen cooperation and collaboration among supply chain partners to achieve close connection and efficient coordination of all links in the supply chain.

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