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Article

Research on Evaluation of Financial Risks in Agricultural Product Supply Chains Based on An Improved DEMATEL Method

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Abstract: In order to improve the rationality, accuracy, and timeliness of decisions on financial risks in agricultural product supply chains, it is necessary to evaluate and control these risks sensibly. In this paper, research is conducted on financial risk factors in agricultural product supply chains, and on this basis a financial risk evaluation index system for such supply chains is built in four identified dimensions – credit risk, market risk, pledge risk, and supply chain relation risk. Next, the weights of risk indexes are measured by means of combined weighting based on subjective F-AHP method and objective CRITIC method. The final risk weight coefficients are then derived with EDAS method. With the aid of an improved DEMATEL method, the agricultural product supply chain financial risk factors are analyzed, and comprehensive impact degrees of different risk factors in agricultural product supply chains are calculated. The calculation results show that financial risks in agricultural product supply chains are highly influenced by cooperation level, performance record, and financial standing and repayment history of borrowing organization. Based on the findings of this paper, appropriate financial risk management and control measures can be developed in light of the key risk factors identified in agricultural product supply chains, thereby providing a valuable reference for financial risk control in agricultural product supply chains.

Keywords: improved DEMATEL method; EDAS method; supply chain finance; risk evaluation

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1. Introduction

Internet-based supply chain finance mainly covers the business fields of credit ex-tension and financing. Using Internet as a platform, it serves core enterprises in supply chains as well as those operating in upstream and downstream links. With a long history behind it, supply chain finance is now in 3.0 Era, which is characterized by close connections between Internet, finance systems, and industrial chains that spur rapid social and economic development, and also by more prominent issues related to risk management and control.

Research on agricultural product supply chain finance has gained traction in the academic world with ever-increasing popularity in recent years. Financial risk control in agricultural product supply chains is intended to guarantee healthy and balanced development of agricultural product supply chain finance through effective risk prevention and mitigation. To achieve this, it stands to reason that a "unified front" for governing agricultural product supply chain finance should be built (Peng, 2018; Xu, 2020; Yu, 2018). More specifically, a risk measurement system needs to be put into place to evaluate and predict financial risks in agricultural product supply chains, to accurately quantify major comprehensive impact of various risk factors, and to determine prerequisites for effective control of such risks.

In the present study, in order to achieve more meaningful and logical evaluation of financial risks in agricultural product supply chains, F-AHP method and CRITIC method are used to obtain subjective and objective combined weights of risk indexes respectively. Following that, EDAS method and an improved DEMATEL method are adopted to analyze financial risks in agricultural product supply chains. Based on calculation of com-prehensive impact degrees, an agricultural product supply chain financial risk measurement model is developed, and risk measurement data is derived. An agricultural product supply chain financial risk control model is subsequently created with the data thus obtained. Measures for controlling these risks are also proposed.

2. Materials and Methods

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

2.1. Development of Agricultural Product Supply Chain Financial Risk Measurement Indexes

545 Internet users were polled through questionnaire survey or expert interview. To make the survey data more targeted, authoritative, and practical, 78 experts in relevant fields were interviewed, including 22 professors and researchers, 26 adjunct professors and associate researchers, and 30 doctoral students. Among 623 questionnaires distributed, 578 were recovered, with a recovery rate of 92.78%. The specific questionnaire survey flowchart is summarized below in Figure 1, covering the survey plan, expert interviews, and relevant studies (Dan et al., 2016; Jin, 2016; Xu et al., 2018; Q. Yang et al., 2016; Zeng et al., 2018; Zhao, 2021).

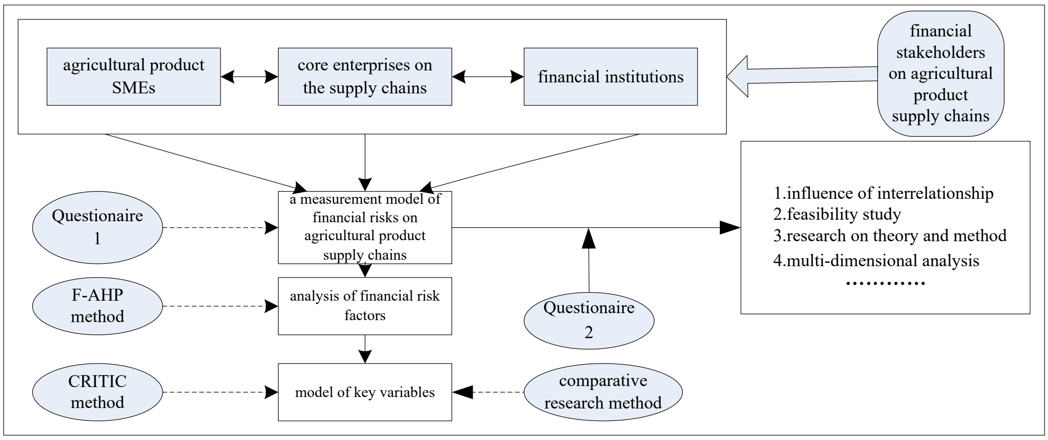

Figure 1. Low chart of questionnaire survey on agricultural product supply chain financial risks.

Based on the above questionnaire survey, expert interviews, and relevant studies (Fang et al., 2017; Higgins, 2010; Huo et al., 2011; Lan et al., 2021; Li et al., 2021; D. Liu et al., 2013; Shi et al., 2019; SZNAJD-WERON & SZNAJD, 2000; Xia et al., 2012; Q. Yang, et al., 2020; Zhang & Zhang, 2009; Zhao & Wang, 2013) four evaluation dimensions, including credit risk, market risk, pledge risk, and supply chain relation risk, are identified as Level 1 indexes, and 13 Level 2 agricultural product supply chain financial risk indexes are defined as well. The system of agricultural product supply chain financial risk measurement indexes is given in Table 1 below.

Table 1. System of agricultural product supply chain financial risk measurement indexes.

Target level	Level 1 index	Level 2 index
Agricultural product supply chain finance risk measurement indexes (B)	Credit risk (B1)	Financial standing and repayment history of borrowing organization (B11)
		Enterprise scale of borrowing organization (B12)
		Management system of borrowing organization (B13)
		Core corporate credit risk (B14)
	Market risk (B2)	Natural risk (B21)
		Risk arising from deterioration of external operation environment (B22)
		Risk due to price change of agricultural products (B23)
	Pledge risk (B3)	Stock status (B31)
		Status of orders (B32)
		Status of accounts receivable (B33)
	Supply chain relation risk (B4)	Supply chain robustness (B41)
		Cooperation level (B42)
		Performance record (B43)

2.2. Creation of an Agricultural Product Supply Chain Financial Risk Evaluation Model Based on An Improved DEMATEL Method

2.2.1. Calculation of Subjective Weight with F-AHP Method

As a fuzzy analytic hierarchy process, F-AHP method features a combination of qualitative and quantitative techniques, and consequently provides both fuzziness and consistency properties. It is capable of quantifying expert assessments objectively and turning qualitative problems into quantitative ones through layer-by-layer decomposition. This method, therefore, adds to the reliability of agricultural product supply chain finance evaluation.

Step 1: Starting from the agricultural product supply chain financial risk measurement indexes, a $n \times n$ fuzzy judgment matrix $B = (b_{ij})_{n\times n}$ is built in consideration of the subjective preferences of experts for n ($n = 13$) risk measurement indexes and the relative importance values assigned to the indexes with F-AHP method as shown in Table 2.

Table 2. Relative importance values assigned to indexes with F-AHP method.

Value	Meaning
0.5	Two elements are equally important
0.6	One element is slightly more important than the other
0.7	One element is significantly important compared with the other
0.8	One element is very important compared with the other
0.9	One element is extremely important compared with the other
0.1, 0.2, 0.3, 0.4	Comparison in reverse order: $b_{ij} + b_{ji} = 1, j = 1,2,3,\cdots,n$

Step 2: In regard to satisfaction consistency and order consistency of the fuzzy matrix, a fuzz consistency matrix $F = (f_{ij})_{n\times n}$ is built out of matrix B , where

$$f_{ij} = \frac{\sum_{j=1}^{n} b_{ij} - b_{ij}}{2n} + 0.5 \tag{1}$$

Step 3: Subjective weights $\chi = (\chi_1, \chi_2, \chi_3, \cdots, \chi_n)$ are calculated, where χ_j represents the weight of the j th risk index. The following equations are then derived:

$$c_j = \frac{2\sum_{i=1}^{n} f_{ji} - 1}{n(n-1)} \tag{2}$$

$$\chi_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \tag{3}$$

2.2.2. Calculation of Objective Weight with CRITIC Method

As an objective weighting process, CRITIC method takes into account not only the information volume of indexes, but also the level of comparison between indexes. It, therefore, leads to more objective, reasonable, and accurate index weight calculations.

Step 1: The agricultural product supply chain financial risks are processed through relativization. High-priority indexes are transformed with Equation (4):

$$g_{ij} = \frac{y_{ij} - \min y_{ij}}{\max y_{ij} - \min y_{ij}} \tag{4}$$

Low-priority indexes are transformed with Equation (5):

$$g_{ij} = \frac{\max y_{ij} - y_{ij}}{\max y_{ij} - \min y_{ij}} \tag{5}$$

Step 2: Negative indexes are converted into positive ones since they need to have the same sign. The conversion is realized with Equation (6):

$$y'_{ij} = \frac{1}{\eta + \max\left|Y_j\right| + y_{ij}} \tag{6}$$

where $\max\left|Y_j\right|$ denotes the maximum of the j th risk index, namely the maximum of the j th row in matrix Y, and η is a coordination coefficient ($\eta = 0.1$ in normal cases). This process yields a positive matrix Y'.

Step 3: Since the meaning of the positive matrix Y' varies with the units adopted, dimensionless treatment of the risk indexes using Equation (7) is required:

$$y''_{ij} = \frac{y'_{ij}}{\sqrt{\sum_{i=1}^{n} (y'_{ij})^2}} \qquad i = 1,2,3,\cdots,m \tag{7}$$

where m is the number of schemes, and n is the number of risk indexes in each scheme. In this way, a standard dimensionless matrix Y'' is generated.

Step 4: Calculation of risk index objective weight. From the standard dimensionless matrix Y'', standard deviation σ_j and correlation coefficient κ_{ij} of different risk indexes can be derived as follows:

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (y''_{ij} - \bar{y}''_j)^2} \tag{8}$$

$$\kappa_j = \frac{\text{cov}(Y_j^{"}, Y_i^{"})}{\sigma_i \sigma_j} \tag{9}$$

where $\bar{y}_j^{"}$ is the average of the j th risk index, and $\text{cov}(Y_j^{"}, Y_i^{"})$ denotes the covariance between the j th row and the i th row of the standard matrix $Y^{"}$.

R_j is used to represent the information volume of agricultural product supply chain financial risk indexes. It is calculated as follows:

$$R_j = \sigma_j \sum_{i=1}^{n'} (1 - \kappa_{ij}) \qquad i = 1,2,3,\cdots,n' \tag{10}$$

where $\sum_{i=1}^{n'} (1 - \kappa_{ij})$ is a quantitative indicator of the degree of conflict between the j th risk index and other risk indexes. The higher the value of R_j, the larger weight of the risk index.

The objective weight w_j is calculated with Equation (11).

$$w_j = \frac{R_j}{\sum_{i=1}^{m} R_j} \qquad (j = 1,2,3,\cdots,n) \tag{11}$$

2.2.3. Method for Determining Combined Weight

The subjective weigh $\chi = (\chi_1, \chi_2, \chi_3, \cdots, \chi_n)$ and objective weights $w = (w_1, w_2, w_3, \cdots, w_n)$ of the measurement indexes can be obtained with F-AHP method and CRITIC method respectively, where $\sum_{j=1}^{n} \chi_j = 1, 0 \le \chi_j \le 1$; $\sum_{j=1}^{n} w_j = 1, 0 \le w_j \le 1$

Assuming W_h is the combined weight of a risk index, the equation $W_h = c_1 w + c_2 \chi$ holds true, where $c_1 + c_2 = 1, c_1 \ge 0, c_2 \ge 0$. By expressing the weighted measurement value of an agricultural product supply chain financial risk with FD_i and the standard value of the j th item of the i th scheme with d_{ij}, the following equation can be established: $FD_i = \sum_{j=1}^{n} \left[(c_1 w_j + c_2 \chi_j) \times d_{ij} \right]^2$. W_h should be selected in such a way to achieve maximum value of FD_i.

$$\max F = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[(c_1 w_j + c_2 \chi_j) \times d_{ij} \right]^2 \tag{12}$$

where $c_1 + c_2 = 1, c_1 \ge 0, c_2 \ge 0$. A Lagrange multiplier function is created as follows based on Equation (12):

$$K(c_1, c_2, c_3) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[(c_1 w_j + c_2 \chi_j) \times d_{ij} \right]^2 + c_3 (c_1 + c_2 - 1) \tag{13}$$

The partial derivatives of c_1, c_2, c_3 are solved with Equation (13):

$$\begin{cases} \dfrac{\partial K(c_1,c_2,c_3)}{\partial c_1} = 2\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(c_1 w_j + c_2\chi_j)\times d_{ij}\right]\times w_j d_{ij} + c_3 \\ \dfrac{\partial K(c_1,c_2,c_3)}{\partial c_2} = 2\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(c_1 w_j + c_2\chi_j)\times d_{ij}\right]\times \chi_j d_{ij} + c_3 \\ \dfrac{\partial K(c_1,c_2,c_3)}{\partial c_3} = c_1 + c_2 - 1 \end{cases} \tag{14}$$

The following results can be derived from Equation (14):

$$\begin{cases} c_1 = \dfrac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(\chi_j^2 - \chi_j w_j)\times d_{ij}^2\right]}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(\chi_j^2 - \chi_j w_j)\times d_{ij}^2\right] + \sum_{i=1}^{m}\sum_{j=1}^{n}\left[(w_j^2 - \chi_j w_j)\times d_{ij}^2\right]} \\ c_2 = \dfrac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(w_j^2 - \chi_j w_j)\times d_{ij}^2\right]}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[(\chi_j^2 - \chi_j w_j)\times d_{ij}^2\right] + \sum_{i=1}^{m}\sum_{j=1}^{n}\left[(w_j^2 - \chi_j w_j)\times d_{ij}^2\right]} \end{cases} \tag{15}$$

In the second round of survey, the data derived from the agricultural product supply chain financial risk measurement index system and corresponding evaluation criteria were supplied to the above-mentioned experts. 78 questionnaires were distributed in this survey, and 69 were recovered, with a recovery rate of 88.46%. The experts were asked to give their measurement of different risk indexes, and their feedback was combined with pertinent literature data for further research (Blackman et al., 2013; Cheng et al., 2016; Z. Liu, 2021; Trkman & McCormack, 2009; Tseng et al., 2021; X. Yang, et al., 2020; Yao & Qin, 2021). 2009AHP method and CRITIC method are used to determine the subject weight and objective weight of different finance risk indexes for agricultural product supply chains respectively, based on which a combined weight $W_h = c_1 w + c_2 \chi$ is obtained for each index. Finally, from the combined weights of different risk indexes, combined weight coefficients are obtained through MATLAB operation, as shown in Table 3.

Table 3. Weights of different indexes in the agricultural product supply chain financial risk measurement index system.

Level 1 index	Level 2 index	Subjective weight	Objective weight	Combined weight
Credit risk (B_1)	Financial standing and repayment history of borrowing organization (B_{11})	0.09	0.10	0.096
	Enterprise scale of borrowing organization (B_{12})	0.05	0.03	0.038
	Management system of borrowing organization (B_{13})	0.07	0.06	0.064
	Core corporate credit risk (B_{14})	0.03	0.03	0.030
Market risk (B_2)	Natural risk (B_{21})	0.03	0.04	0.036
	Risk arising from deterioration of external operation environment (B_{22})	0.06	0.08	0.072
	Risk due to price change of agricultural products (B_{23})	0.04	0.04	0.04
Pledge risk (B_3)	Stock status (B_{31})	0.05	0.04	0.044
	Status of orders (B_{32})	0.08	0.07	0.074
	Status of accounts receivable (B_{33})	0.03	0.04	0.036
Supply chain relation risk (B_4)	Supply chain robustness (B_{41})	0.08	0.07	0.074
	Cooperation level (B_{42})	0.21	0.23	0.222
	Performance record (B_{43})	0.18	0.17	0.174

2.2.4. Method for Determining Index Weight Based on EDAS

Because experts may find it very difficult to evaluate the agricultural product supply chain financial risk measurement index system objectively and accurately, an index weight determination method based on EDAS is proposed in the present study, thus realizing more objective, reasonable, and logical measurement results.

In this method, a probabilistic language term set is introduced and expressed as follows: $Q(p)=\left\{Q^{(k)}(p^{(k)})\middle|Q^{(k)}\in S, p^{(k)}\geq 0, k=1,2,\cdots,\kappa Q(p), \sum_{k=1}^{\kappa Q(p)} p^{(k)}\leq 1\right\}$, where $Q^{(k)}(p^{(k)})$ is a language term $Q^{(k)}$ containing probabilistic information $p^{(k)}$. $\kappa Q(p)$ denotes the number of language terms in $Q(p)$, and $\kappa Q(p)=K$. Then the entropy of $Q(p)$ needs to meet the following requirements:

(1) $0\leq E(Q(p))\leq 1$;

(2) When $g(Q(p))=0$ or $g(Q(p))=1$, if $p^{(k)}=1$, $E(Q(p))=0$;

(3) When and only when $\kappa Q(p)=2$, if $p^{(1)}=p^{(2)}=\frac{1}{2}$ and $g(Q^{(1)})+g(Q^{(2)})=1$, $E(Q(p))=1$.

Probabilistic language entropy can be defined based on hesitant fuzzy language entropy and probabilistic language equivalence transformation function:

$$E(Q(p))=\frac{1}{K(\sqrt{2}+1)}\sum_{k=1}^{K}(\sin\frac{\pi p^{(k)}}{2}+\cos\frac{\pi p^{(k)}}{2}+\sin\frac{\pi(g(Q^{(k)})+g(Q^{(K-k+1)})}{2} + \cos\frac{\pi(1-g(Q^{(k)})-g(Q^{(K-k+1)})}{2}-1) \tag{16}$$

It is assumed in this study that 13 risk evaluation indexes are selected by an agricultural product supply chain finance emergency department, their weight being denoted by $\upsilon=(\upsilon_1,\upsilon_2,\cdots,\upsilon_{13})^T$,

Eight experts with relevant background can be selected and asked to assign language evaluation values to the 13 risk measurement indexes, and a decision maker can make use of the following set to measure agricultural product supply chain financial risk indexes:

$$S=\begin{Bmatrix} s_{-4},s_{-3}=\text{very low},s_{-2}=\text{low},s_{-1}=\text{slightly low},s_{0}=\text{medium} \\ s_{4}=\text{extremely high},s_{3}=\text{very high},s_{2}=\text{high},s_{1}=\text{slightly high} \end{Bmatrix}$$

Based on the language evaluation values offered by the experts, a probabilistic language decision matrix $R=[Q_{ip}(p)]_{m\times n}$ can be created, as shown in Table 4.

Table 4. Probabilistic language decision matrix based on expert evaluation.

Expert	B11	B12	B13	B14	B21	B22	B23	B31	B32	B33	B41	B42	B43
1	s_{1}, s_{2}	s_{2},s_{3}	s_{0},s_{1}	s_{-1},s_{0}	s_{3},s_{4}	s_{0},s_{1}	s_{-4},s_{-3}	s_{-1},s_{0}	s_{-2},s_{-1}	s_{0},s_{1}	s_{2},s_{3}	s_{-3},s_{-2}	s_{-1},s_{0}
2	s_{-1},s_{0}	s_{3},s_{4}	s_{0},s_{1}	s_{-4},s_{-3},	s_{2},s_{3}	s_{0},s_{1}	s_{-1},s_{0}	s_{3},s_{4}	s_{0},s_{1}	s_{3},s_{4}	s_{0},s_{1}	s_{0},s_{1}	s_{-4},s_{-3},
3	s_{0},s_{1}	s_{-1},s_{0}	s_{-2},s_{-1}	s_{0},s_{1}	s_{-1},s_{0}	s_{0},s_{1}	s_{0},s_{1}	s_{2},s_{3}	s_{-3},s_{-2}	s_{-1},s_{0}	s_{3},s_{4}	s_{-4},s_{-3}	s_{-4},s_{-3}
4	s_{0},s_{1}	s_{0},s_{1}	s_{-1},s_{0}	s_{0},s_{1}	s_{-4},s_{-3}	s_{0},s_{1}	s_{3},s_{4}	s_{0},s_{1}	s_{3},s_{4}	s_{-4},s_{-3}	s_{2},s_{3}	s_{0},s_{1}	s_{0},s_{1}
5	s_{-2},s_{-1}	s_{0},s_{1}	s_{-4},s_{-3}	s_{-3},s_{-2}	s_{0},s_{1}	s_{-2},s_{-1}	s_{0},s_{1}	s_{-4},s_{-3}	s_{2},s_{3}	s_{0},s_{1}	s_{0},s_{1}	s_{0},s_{1}	s_{0},s_{1}
6	s_{-1},s_{0}	s_{3},s_{4}	s_{0},s_{1}	s_{-4},s_{-3}	s_{0},s_{1}	s_{-1},s_{0}	s_{3},s_{4}	s_{0},s_{1}	s_{2},s_{3}	s_{0},s_{1}	s_{0},s_{1}	s_{2},s_{3}	s_{3},s_{4}
7	s_{-4},s_{-3}	s_{2},s_{3}	s_{0},s_{1}	s_{-1},s_{0}	s_{0},s_{1}	s_{2},s_{3}	s_{2},s_{3}	s_{3},s_{4}	s_{0},s_{1}	s_{0},s_{1}	s_{3},s_{4}	s_{0},s_{1}	s_{2},s_{3}
8	s_{0},s_{1}	s_{-1},s_{0}	s_{0},s_{1}	s_{0},s_{1}	s_{3},s_{4}	s_{0},s_{1}	s_{-1},s_{0}	s_{0},s_{1}	s_{0},s_{1}	s_{-3},s_{-2}	s_{0},s_{1}	s_{-4},s_{-3}	s_{0},s_{1}

Next, the probabilistic language decision matrix is standardized. Equations (17) and (18) are then used to calculate weights of risk evaluation indexes, and the results obtained in the present research are listed in Table 5.

$$\begin{cases} \max H(w)=\sum_{i=1}^{m}\left(\frac{1}{m-1}\sum_{l=1,l\neq i}^{n}CE(Q_{ij}(p),Q_{lj}(p))+(1-E(Q_{ij}(p))w_{j}\right. \\ \sum_{j=1}^{n}\upsilon_{j}^{2}=1,0\leq w_{j}\leq 1 \end{cases} \tag{17}$$

$$\upsilon_{j}=\frac{\sum_{i=1}^{m}[(\frac{1}{m-1}\sum_{l=1,l\neq i}^{n}CE(Q_{ij}(p),Q_{lj}(p))+(1-E(Q_{ij}(p))]}{\sum_{j=1}^{n}\sum_{i=1}^{m}[(\frac{1}{m-1}\sum_{l=1,l\neq i}^{n}CE(Q_{ij}(p),Q_{lj}(p))+(1-E(Q_{ij}(p))]} \tag{18}$$

where $\sum_{j=1}^{m}\upsilon_{j}=1,0\leq\upsilon_{j}\leq 1$.

Table 5. Weights of the risk measurement index system based on EDAS.

B11	B12	B13	B14	B21	B22	B23	B31	B32	B33	B41	B42	B43
0.0934	0.0312	0.0571	0.0268	0.0334	0.0626	0.0265	0.0435	0.0664	0.0315	0.0667	0.2789	0.1820

In order to make these expert-derived weights more rational, accurate, and logical, and to reduce randomness, the following combined weight equation concerning expert evaluation is adopted:

$$w_{z}^{'}=\alpha_{\alpha}w_{h}+\beta_{\beta}\upsilon_{i} \tag{19}$$

Delphi method is used again to analyze the weight coefficients of $\alpha_{\alpha},\beta_{\beta}$ based on data provided by the eight experts, following which the data from every expert is reviewed and corrected. The revised data is then delivered to the experts so that they can offer opinions on data refinement. This process occurs iteratively until the result of $\alpha_{\alpha}=0.6,\beta_{\beta}=0.4$ is achieved unanimously.

The resulting final combined weight coefficients of the agricultural product supply chain financial risk indexes in our study are shown in Table 6.

Table 6. Final combined weights in the risk measurement index system.

B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}
0.09496	0.03528	0.06124	0.02872	0.03496	0.06824	0.0346	0.0438	0.07096	0.0342	0.07108	0.24476	0.1772

2.2.5. Calculation of the Comprehensive Impact Matrix Based on an Improved DEMATEL Method

Shaped by a variety of factors, financial risks in agricultural product supply chains have uncertainties. In order to reduce the number of elements in the agricultural product supply chain financial risk system and to simplify relations between elements, we perform general evaluation from a holistic perspective using an improved DEMATEL method with the following steps:

Step 1: The values of 0, 0.2, 0.4, 0.6, 0.8, and 1 are used to represent "no impact", "very weak impact", "weak impact", "average impact", "strong impact", and "very strong impact" respectively, and the values of 0.1, 0.3, 0.5, 0.7, and 0.9 correspond to impact degrees between them. By correcting these values based on expert evaluation results and relevant weights, an original matrix of agricultural product supply chain financial risk factors can be generated.

Step 2: The data in the agricultural product supply chain financial risk factor matrix also receives dimensionless treatment. Initial value operators are used to generate an initial value matrix. Let $X_\hbar = (x_\hbar(1), x_\hbar(1), \cdots, x_\hbar(13))$ be the behavior sequence of factor $X_\hbar$ with D_1 being an operator in the sequence, and we can calculate as follows:

$$X_\hbar D_1 = (x_\hbar(1)d_1, x_\hbar(2)d_1, \cdots, x_\hbar(13)d_1) \tag{20}$$

where $x_\hbar(k)d_1 = \frac{x_\hbar(k)}{x_\hbar(1)}, x_\hbar(1) \neq 0, k = 1,2,\cdots,13$. Here D_1 is called initial value operator. The behavior sequence of the main system risk factor is denoted by X_0, and that of relevant agricultural product supply chain financial risk factors are denoted by $X_\hbar$ and X_j. If $r_{0\hbar} \geq r_{0j}$ holds true for the corresponding grey relation degree, we say $X_\hbar$ precedes over X_j, and this relation is expressed as $X_\hbar \succ X_j$, where "$\succ$" is the grey relation sequence derived from the grey relation.

Step 3: Calculation of maximum and minimum in the initial value matrix of agricultural product supply chain financial risk factors.

$\Delta_{0\hbar}(s) = |x_0(s) - x_\hbar(s)|$, where $s = 1,2,\cdots,13$; $\hbar = 1,2,\cdots,13$

Step 4: Calculation of correlation coefficient and derivation of direct impact matrix. ρ is used to denote the identification coefficient. In the value range of (0, 1), the lower the ρ value, the higher degree of identification. If $\{x_0(s)\}$ corresponds to a data column of optimal value, a larger $\varsigma_\hbar(s)$ is desired. If $\{x_0(s)\}$ corresponds to a data column of worst value, a smaller $\varsigma_\hbar(s)$ is desired. Suppose $\rho = 0.5$, and we can obtain the following result:

$$\varsigma_\hbar(s) = \frac{\min_\hbar \min_s |x_0(s) - x_\hbar(s)| + \rho \cdot \max_\hbar \max_s |x_0(s) - x_\hbar(s)|}{|x_0(s) - x_\hbar(s)| + \rho \cdot \max_\hbar \max_s |x_0(s) - x_\hbar(s)|}, \text{ where } s = 1,2,\cdots,13 \tag{21}$$

The values of $\varsigma_\hbar(1)$, $\varsigma_\hbar(2)$, ……, $\varsigma_\hbar(13)$ are calculated for $\hbar = 1$. Similarly, correlation coefficients for $\hbar = 2,3,\cdots,13$ are all derived. A direct impact matrix of agricultural product supply chain financial risk factors can then be generated, as shown in Table 7.

Table 7. Direct impact matrix of agricultural product supply chain financial risk factors.

No.	B11	B12	B13	B14	B21	B22	B23	B31	B32	B33	B41	B42	B43
B11	0.0000	0.1997	0.1807	0.1997	0.6467	0.0571	0.1443	0.5952	0.2071	0.0810	0.2933	0.8467	0.8265
B12	0.8745	0.0000	0.1499	0.1885	0.5408	0.4048	0.3453	0.2743	0.4267	0.7600	0.2386	0.6500	0.6345
B13	0.7349	0.1718	0.0000	0.1718	0.4833	0.7971	0.1374	0.1569	0.5408	0.6267	0.2871	0.7967	0.6978
B14	0.6633	0.6467	0.2414	0.0000	0.3453	0.7867	0.2414	0.3586	0.4333	0.2157	0.3471	0.8629	0.7552
B21	0.7967	0.6754	0.4048	0.4894	0.0000	0.6544	0.4048	0.5833	0.4533	0.3667	0.6643	0.8933	0.6136
B22	0.8633	0.6467	0.6033	0.1600	0.7867	0.0000	0.0571	0.2667	0.2414	0.0810	0.2667	0.7500	0.7667
B23	0.6600	0.1810	0.4892	0.4373	0.0000	0.0910	0.0000	0.6444	0.4048	0.7944	0.6444	0.8300	0.3129
B31	0.7680	0.2643	0.6544	0.7899	0.3453	0.4333	0.2071	0.0000	0.2186	0.7643	0.7643	0.7720	0.6233
B32	0.6964	0.5952	0.4543	0.6000	0.1374	0.3810	0.2933	0.7136	0.0000	0.7842	0.7136	0.5714	0.7515
B33	0.5680	0.4267	0.7871	0.3386	0.2414	0.5873	0.0012	0.6544	0.4048	0.0000	0.4533	0.6967	0.7598
B41	0.4129	0.1200	0.6000	0.5733	0.4048	0.4043	0.3453	0.6467	0.0571	0.2667	0.0000	0.8885	0.7269
B42	0.8133	0.4000	0.5408	0.6267	0.2871	0.7871	0.1374	0.6544	0.4048	0.4833	0.4533	0.0000	0.6157
B43	0.6129	0.2543	0.2871	0.7600	0.2386	0.2667	0.2414	0.0810	0.7971	0.4592	0.6433	0.7512	0.0000

Step 5: Construction of a comprehensive impact matrix: Assuming G_x is the direct impact matrix of agricultural product supply chain financial risk factors, standardization of this matrix will lead to a standard direct matrix G_{xy}.

$$f_x = \frac{1}{\max\limits_{1\le \hbar \le n} \sum_{j=1}^{n} G_{x_{\hbar j}}}, \quad G_{xy} = f_x G_x \tag{22}$$

A comprehensive impact matrix B_{xy} can then be built:

$$B_{xy} = G_{xy}(I - G_{xy})^{-1} \tag{23}$$

where I is a unit matrix. With the aid of MATLBA software, the comprehensive impact matrix of B_{xy} is obtained, as shown in Table 8.

Table 8. Comprehensive impact matrix of agricultural product supply chain financial risk factors.

No.	B11	B12	B13	B14	B21	B22	B23	B31	B32	B33	B41	B42	B43
B11	0.3278	0.2093	0.2369	0.2553	0.2709	0.2394	0.1241	0.2997	0.2193	0.2260	0.2705	0.4670	0.4264
B12	0.5151	0.2240	0.2826	0.2956	0.3027	0.3311	0.1705	0.3129	0.2886	0.3582	0.3112	0.5234	0.4783
B13	0.5078	0.2559	0.2675	0.2983	0.3037	0.3908	0.1447	0.3010	0.3088	0.3435	0.3217	0.5507	0.4967
B14	0.5193	0.3265	0.3092	0.2868	0.2974	0.4007	0.1667	0.3366	0.3053	0.3060	0.3412	0.5792	0.5203
B21	0.6110	0.3700	0.3818	0.4041	0.2933	0.4378	0.2122	0.4198	0.3491	0.3763	0.4350	0.6681	0.5778
B22	0.5165	0.3089	0.3341	0.2904	0.3393	0.2796	0.1358	0.3052	0.2669	0.2710	0.3120	0.5366	0.4944
B23	0.4866	0.2449	0.3315	0.3310	0.2310	0.2971	0.1223	0.3621	0.2827	0.3667	0.3632	0.5473	0.4396
B31	0.5752	0.3007	0.3968	0.4222	0.3231	0.3951	0.1752	0.3220	0.3039	0.4031	0.4260	0.6232	0.5529
B32	0.5730	0.3449	0.3757	0.4047	0.2982	0.3881	0.1893	0.4200	0.2767	0.4163	0.4266	0.6038	0.5742
B33	0.5096	0.2969	0.3844	0.3362	0.2864	0.3825	0.1349	0.3741	0.3043	0.2796	0.3577	0.5633	0.5263
B41	0.4597	0.2408	0.3417	0.3493	0.2860	0.3399	0.1710	0.3548	0.2430	0.2963	0.2783	0.5563	0.4893
B42	0.5559	0.3049	0.3626	0.3815	0.3032	0.4161	0.1578	0.3866	0.3112	0.3509	0.3682	0.4919	0.5252
B43	0.4767	0.2586	0.2967	0.3674	0.2597	0.3162	0.1573	0.2867	0.3319	0.3168	0.3584	0.5316	0.3929

Step 6: Analysis of agricultural product supply chain financial risk factors: From the comprehensive impact matrix of agricultural product supply chain financial risk factors, centrality degree ($\mathrm{Lm}_{\hbar}$) and causality degree ($\mathrm{Lu}_{\hbar}$) are derived through the following equations, where $\mathrm{LD}_{\hbar}$ and $\mathrm{LR}_{\hbar}$ represent impact degree and vulnerability degree respectively.

$$\mathrm{LD}_{\hbar}=\sum_{j=1}^{n}t_{\hbar j}\quad(\hbar=1,2,\cdots,13) \tag{24}$$

$$\mathrm{LR}_{\hbar}=\sum_{j=1}^{n}t_{j\hbar}\quad(\hbar=1,2,\cdots,13) \tag{25}$$

$$\mathrm{Lm}_{\hbar}=\mathrm{LD}_{\hbar}+\mathrm{LR}_{\hbar}\quad(\hbar=1,2,\cdots,13) \tag{26}$$

$$\mathrm{Lu}_{\hbar}=\mathrm{LD}_{\hbar}-\mathrm{LR}_{\hbar}\quad(\hbar=1,2,\cdots,13) \tag{27}$$

3. Results

Based on the above analysis, the impact degree and vulnerability degree values of agricultural product supply chain financial risk factors are calculated with Equations (24) - (27), as shown in Table 9, and the centrality degree and causality degree values are given in Table 10.

Table 9. Impact degree and vulnerability degree of agricultural product supply chain financial risk.

No.	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}
Impact degree	3.5726	4.3942	4.4909	4.6951	5.5364	4.3906	4.4059	5.2194	5.2914	4.7363	4.4063	4.9160	4.3509
Vulnerability degree	6.6341	3.6862	4.3017	4.4228	3.7950	4.6142	2.0615	4.4815	3.7917	4.3107	4.5701	7.2423	6.4941

Table 10. Centrality degree and causality degree of agricultural product supply chain financial risk.

No.	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{31}	B_{32}	B_{33}	B_{41}	B_{42}	B_{43}
Centrality degree	10.2067	8.0805	8.7926	9.1179	9.3314	9.0048	6.4674	9.7009	9.0831	9.0470	8.9764	12.1583	10.8450
Causality degree	3.0615	0.7080	0.1893	0.2723	1.7414	0.2236	2.3444	0.7379	1.4998	0.4256	0.1638	2.3264	2.1432

With the centrality degree and causality degree values, a causal relation graph is plot ted, as shown in Figure 2:

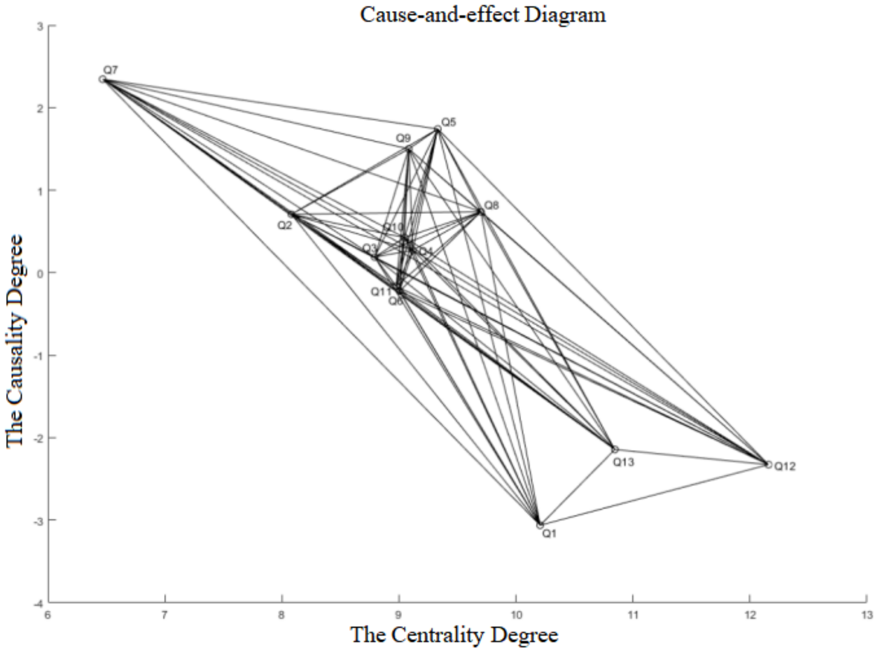

Figure 2. Causal relation of comprehensive impact of agricultural product supply chain financial risk factors.

Based on the combined weight coefficients and calculation results of DEMATEL method, the product of a centrality degree and corresponding weight of an agricultural product supply chain financial risk factor is calculated as the comprehensive impact degree of that risk factor. The comprehensive impact degree serves as an accurate measure of the importance of risk factors, and helps reduce subjectivity of combined weight coefficients and improve DEMATEL method. The multiplication operation is expressed as follows:

$$z_{\hbar} = Lm_{\hbar} \cdot w_z^{'} \quad (\hbar = 1,2,\cdots,13) \tag{28}$$

where $w_z^{'}$ is a weight of an agricultural product supply chain financial risk measurement index in the final combined weight coefficient method. The calculation results are given in Table 11:

Table 11. Comprehensive impact degree of agricultural product supply chain financial risk factors.

Impact factor	**B_{11}**	**B_{12}**	**B_{13}**	**B_{14}**	**B_{21}**	**B_{22}**	**B_{23}**	**B_{31}**	**B_{32}**	**B_{33}**	**B_{41}**	**B_{42}**	**B_{43}**
$z_{\hbar}$	0.9692	0.2851	0.5385	0.2619	0.3262	0.6145	0.2238	0.4249	0.6445	0.3094	0.6380	2.9759	1.9217
Ranking	3	11	7	12	9	6	13	8	4	10	5	1	2

Centrality degree reflects the importance of different impact factors in the course of agricultural product supply chain financial risk evaluation. It can be seen from Figure 2 that the risk indexes of cooperation level, performance record, financial standing and repayment history of borrower organization, and stock status have a high centrality degree that exceeds 9.5. They belong to supply chain relation risk, credit risk, and pledge risk respectively. This indicates that these risk factors play a more significant role in agricultural product supply chain financial risk evaluation.

Based on the comprehensive degrees of agricultural product supply chain financial risk factors listed in Table 9, cooperation level, performance record, financial standing and repayment history of borrower organization, status of orders, supply chain robustness, and risk arising from deterioration of external operation environment are main agricultural product supply chain financial risk impact factors, among which cooperation level, performance record, financial standing and repayment history of borrower organization have a higher comprehensive impact degree. Hence, stricter control of supply chain relation risk and credit risk is required.

4. Discussion

Current management of agricultural product supply chain financial risks is still confronted with many challenges, such as difficult risk warning, delayed risk monitoring, and lack of coordination by financial regulatory authorities for agricultural product supply chains. It is therefore imperative for the government to reinforce agricultural product supply chain financial risk control (Fan et al., 2017; Jing et al., 2021; J. Liu et al., 2019). The government should build and refine a financial information sharing platform for agri-cultural product supply chains, and improve warning, intervention, response, and post-event accountability mechanisms for relevant risks, thereby laying systematic groundwork for control of such risks. It is advisable for the government to make use of block chain technology to help agricultural product SMEs improve their risk management capabilities, and to refine the government regulatory system. The block chain concepts and principles may aid optimization of financial models in agricultural product supply chains (Song et al., 2017; M. Yang et al., 2021), and may be coupled with experiences of managers to facilitate risk control in agricultural product SMEs. The specific risk control mechanisms are illustrated in Figure 3:

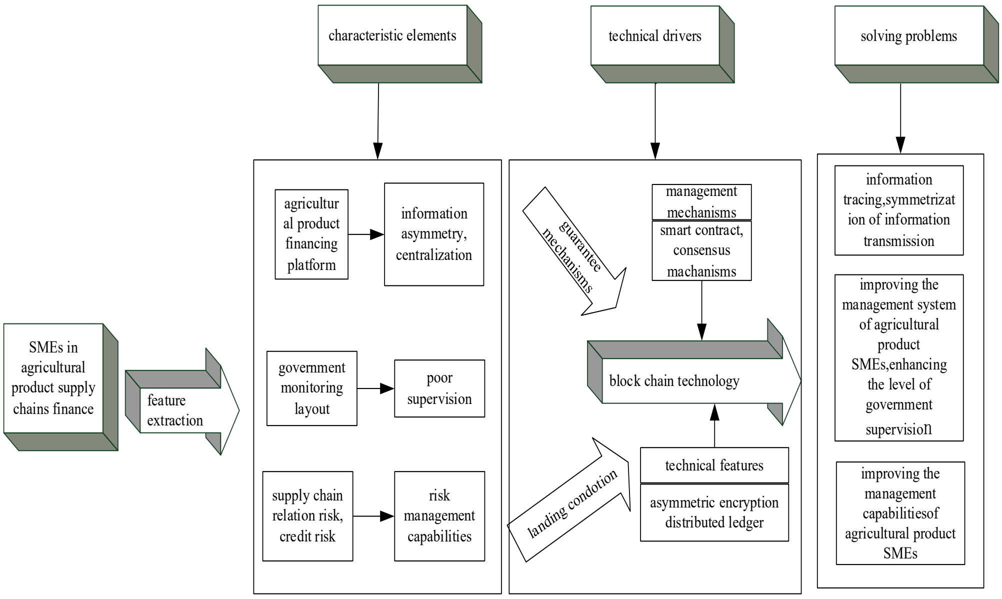

Figure 3. Finance risk control mechanisms based on block chain technology for agricultural product supply chains.

Block chain technology can give full play to network effects and application syner-gies between users, and help build a real-time information sharing database. Conse-quently, a more flexible and practical knowledge configuration can be created to provide assurance for agricultural product SMEs in their risk prevention and control. The intelli-gent coordination of risk control between banks, core enterprises, and agricultural product SMEs will also be boosted (Y. Liu & Cui, 2016; Luo & Chen, 2016; Wu et al., 2022). Moreover, block chain technology contributes to effectiveness and confidentiality of risk control, as well as traceability and efficient transmission of pertinent knowledge and information. Thanks to tamper-proof functions and intelligent contracts enabled by block chain technology, the government is able to provide agricultural product SMEs with different paths for mitigating various risks, improving their risk immunity and making sure that all supply chain financial risks are controllable and manageable.

5. Conclusions

Based on research on agricultural product supply chain financial risk impact factors, four dimensions of the agricultural product supply chain financial risk measurement in-dex system are identified – credit risk, market risk, pledge risk, and supply chain relation risk. Weight measurement is performed on the risk indexes with subjective F-AHP method and objective CRITIC method, and the final risk weight coefficients are obtained with EDAS method. Next, an improved DEMATEL method is adopted to analyze agri-cultural product supply chain financial risk factors, and the comprehensive impact de-grees of different risk factors are calculated. According to findings of the present research, cooperation level, performance record, financial standing and repayment history of bor-rower organization, status of orders, supply chain robustness, and risk arising from de-terioration of external operation environment are main financial risk impact factors for agricultural product supply chains.

Recommendations for the government: In the context of Finance 4.0 for supply chains, the government can make use of fintech such as block chain to help agricultural product SMEs improve their risk monitoring, prevention and control capabilities. By exploiting the tamper-proof and de-centralized nature of block chain technologies, the government may create a supply chain financial risk monitoring system to enable transaction tracking and automatic monitoring among agricultural products SMEs, which will mitigate the credit risks confronted by them. In the meanwhile, it is necessary to grant stronger sup-port to agricultural product SMEs by creating a favorable financing environment and improving the credit extension system to solve their financing difficulties. Besides, given the unstable operation of some agricultural product SMEs, the government should promote establishment of associations of SMEs and micro enterprises. The members of such associations may support and cooperate with each other for mutual benefit. Through creation of credit guarantee funds, it is possible to make up for core enterprise credit guarantee losses. Recommendations for financial institutions: A risk monitoring and punishment management system should be set up to urge agricultural product SMEs to share information effectively. This will contribute to better un-derstanding of the operation and financial status of agricultural product SMEs. Recommendations for agricultural products: They should give priority to financial and accounting transparency and improve credibility of information disclosure to ensure standard statement of their internal financial information.

The present research makes certain breakthrough and innovation in highlighting re-search viewpoints, promoting research concepts, and integrating research methods. The scope of the re-search extends to the realms of agricultural product supply chain man-agement, risk management, information economics, and supply chain finance. In partic-ular, the in-depth research on supply chain risk management may provide more experi-ences and reproducible risk control patterns and paths for financial institutions. On the other hand, there are certain aspects in this research that need to be improved in the future, and a more insightful research outlook needs to be developed.

Future research direction and outlook: The research on agricultural product supply chain fi-nancial risks may evolve from QCA analysis to MEM study. While QCA analysis involves relevant risk impact factors, MEM analysis covers collection, calculation, and visualization of credit data of research objects. These two methods may be combined in the future to enable deep study on some risk indexes that are hard to quantify, to better verify correctness of conclusions, and to give birth to long-term mechanisms for preventing and mitigating risks.

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