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AN INTEGRATED BWM-CRITIC APPROACH BASED ON NEUTROSOPHIC SET FOR SUSTAINABLE SUPPLY CHAIN FINANCE RISK EVALUATION

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Abstract. *How to scientifically identify and analyze complex risk factors to implement effective prevention and control measures has become one of the focuses of sustainable supply chain finance (SSCF) research. This paper aims to develop a framework for SSCF risk evaluation. To this end, an integrated neutrosophic multi-criteria group decision-making (MCGDM) approach is proposed to deal with the uncertainty and ambiguity based on the best-worst method (BWM), criteria importance through inter-criteria correlation (CRITIC) and prospect theory (PT). Through a representative literature review and expert survey, forty-two risk criteria were identified from five main sustainability dimensions for the construction of evaluation index system in this paper. The BWM method and CRITIC are used to obtain the subjective importance degree and objective weight of criteria respectively. Meanwhile, an extended similarity measure is developed to determine the weights of decision-makers (DMs) that fully consider the differences in preferences and characteristics among them. Then, according to the psychological behavior of DMs on risk factors, the comprehensive prospect value is determined through prospect theory to find the optimal alternative. Finally, the proposed integrated framework is successfully implemented in a practical example, and the results show that the degree of information sharing is the most important risk criterion. The findings also provide a theoretical foundation for enhancing the understanding of SSCF risk evaluation.*
Keywords: Sustainable supply chain finance, Risk evaluation index system, Prospect theory, BWM-CRITIC, MCGDM

1. Introduction.

Supply chain finance (SCF) practices have experienced rapid development over the past few years with its structured way of operating. SCF can enable multiple organizations in the supply chain (SC) to commit to sharing relationship resources, products, information and risks on the basis of medium and long-term contracts, and jointly create value by optimizing, guiding and controlling the flow of financial resources from an SC perspective [1,2]. Although the operating efficiency and profit growth point of the participating entities have been improved, the overall characteristics of SCF also magnify the risk spread caused by the poor management of individual business in the SC. Because of competition increasing, information asymmetry and the influx of unlimited new enterprises, the uncertainties and risks of the organization's SC were increased [3]. In this case, if the risk information system is not improved with the business upgrade, increasing the proportion of enterprises participating in SCF will increase the risk exposure of financial institutions [4]. Therefore, risk management of SCF should not only

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strengthen the construction of information sharing and control capabilities, but also pay close attention to the sustainable management abilities of enterprises to achieve a balance between bank credit and credit guarantees. There is growing interest among academics in optimize traditional SCF model from the perspective of sustainable development, that is, seeking an effective balance based on the triple bottom line (TBL) (economic, social and environmental) while realizing business development [5]. The practice of sustainable supply chain finance (SSCF) not only serves to ensure sustainability itself, but also improves the performance of risk management in the long term to help companies avoid economic and reputational damage. In order to guarantee a sustainability of the SCF, consideration of the risk management is a critical point. Risk identification and risk evaluation for SSCF are the premise of risk management; constructing a scientific and reasonable risk evaluation index system is also one of the research hotspots. While traditional risk mitigation strategies can yield short-to-medium-term benefits, sustainability efforts target long-term future benefits and are an effective complement to risk prevention and control systems [6]. Xu et al. [7] constructed a risk decision-making model based on seven identification factors. Yang et al. [8] identified and predicted the factors affecting the credit risk of small and medium-sized enterprises (SMEs) in SSCF through lasso-logistic regression model, and constructed an index system containing twenty risk sub-variables from three dimensions. Tseng et al. [5] also developed an SSCF evaluation model under uncertain environment based on social, economic and environmental measures.

Multi-criteria group decision-making (MCGDM) techniques can effectively solve this complex problem which is characterized by multi-category risk criteria and difficult to quantify. On the basis of identifying risk criteria, Moktadir et al. [9] adopted the method of subjective weight determination to evaluate the importance of each relevant risk factor. In fact, due to the influence of many ambiguous and complicated factors in the process of risk evaluation, it is often difficult to fully and truly express the DMs' cognition preference of risk criteria with precise numbers only. The MCGDM model can be applied to different uncertain environments according to the complexity of the risk evaluation-based problem [10,11]. There is also study that introduces neutrosophic set into the evaluation of sustainable financing policies aimed at reducing environmental pollution [12]. Neutrosophic set can fully consider and quantify the inherent uncertainty, fuzziness and inaccuracy in decision-making, and expand the decision-making environment of SSCF risk evaluation from a philosophical perspective.

The existing studies on criteria weights or DM weights determination methods are mainly divided into two categories, the subjective weighting method and the objective weighting method. From an objective point of view, Liu and Zhang [13] established a CCSD-based decision model to derive the weights of criteria with partially known or completely unknown information. Some other subjective or objective weight decision methods have also been applied to the expression of uncertain weight information in various complex environments [14-16]. Considering that objective evaluation information and DM subjective preference have a significant impact on the relative importance of uncertain risk criteria, both objective and subjective weights should be considered to make decisions more convincing. In addition, how to reasonably allocate the proportion of subjective and objective weights in the integration process is also worthy of attention. Liu et al. [17] proposed a linear weighed method to integrate the two types of criteria weights but set their weight coefficient to be equal, which considered the formal difference of the weights while ignoring their essential difference. In all studies related to SSCF risk evaluation, choosing an appropriate ranking approach is one of the difficulties related to whether a reasonable decision result can be obtained. Many representative ranking methods have been developed to solve such kind of MCGDM problem, such as fuzzy TOPSIS (technique in order of preference by similarity to ideal solution) [5], logistic regression-based model [18] and TODIM (an acronym in Portuguese for Interactive and Multicriteria Decision Making) [19]. However, the psychological activities and subjective risk behavior preferences of DMs for different alternatives are not fully expressed in these methods. In this case, PT [20] was proposed to express the psychological state of DMs when faced with gains and losses, in which the prospect value is represented by value function and weight function.

1.1. **Motivation.** The existing studies have made significant contributions to exploring the role of SSCF on the basis of TBL and decision-making evaluation of related risks criteria. However, there are some limitations that can be described as follows. 1) Some studies of evaluating SSCF risk have some deficiency in considering the integration of subjective and objective weight of risk criteria to promote the comprehensiveness of decision-making. Also, there is an absence of considering the characteristic's differences of DMs, while many studies assumed that they all have the same degree of influence on the determination of optimal alternative, which is obviously unrealistic and may lead to inaccurate results. 2) Although PT has been well associated with several MCGDM approaches [21,22], and widely used in fuzzy environments such as hesitant fuzzy [23] and intuitionistic fuzzy [24], there are still few studies on SSCF risk evaluation in combination with neutrosophic set under high uncertainty. Therefore, it is of great research significance to apply PT to the risk assessment of SSCF in a neutrosophic environment that comprehensively considers subjective, objective criteria information and DM characteristics. 3) The proposed integrated PT-BWM-CRITIC approach allows to obtain more accurate and reliable risk evaluation results when considering the characteristic differences and risk preferences of DMs under neutuosophic and incomplete decision information.

1.2. **Novelty of the proposed model.** The main contributions of this paper can be presented below.

1) An integrated approach using extended similarity measure with the BWM-CRITIC method is developed under neutrosophic environment to handle the risk evaluation problem of SSCF with unknown weight information.

2) This paper constructs a comprehensive SSCF risk evaluation index system, which considers multi-dimensional risk criteria from social, economic, environmental, sustainable characteristics of SC and information related.

3) The uniformity entropy theory, by using the outcomes of BWM as well as CRITIC, is utilized to integrate subjective and objective weights of risk attributes under nuetrosophic environment. Further, the extended similarity measure is used for proper calculation of DMs' importance weights in terms of neutrosophic information.

4) The validity and applicability of the proposed PT-BWM-CRITIC approach are examined by a practical example concerning the risk evaluation of SSCF.

The remainder of this paper is organized as follows. In the next section, we briefly recall some of the fundamental concepts and operations about neutrosophic set and decision-making methods. The construction process of the proposed evaluation index system and the steps of the neutrosophic-based approach are detailed in Section 3 to handle the SSCF risk evaluation problem. Our methods are applied to a practical example in Section 4. Section 5 discusses the results and verifies the superiorities and robustness of the proposed model through comparative analysis and sensitivity analysis. Finally, in Section 6, the concluding remarks and possible future studies are given.

2. **Basic Theory of the Proposed MCGDM Method for SSCF Risk Evaluation.** In this paper, we present a series of methods for handling the MCGDM problem based on the neutrosophic set with incomplete information to improve the accuracy of the risk

evaluation process. This section is composed of five sub-sections to review some basic theories of these methods: BWM-CRITIC utilized to calculate the subjective and objective weights of risk criteria; extended similarity measures applied to determining the weights of DMs; PT employed to select the optimal alternative.

2.1. **Neutrosophic set.**

Definition 2.1. [25] *Let X be a set of elements, with a generic element in X denoted by x and $x \in X$. A neutrosophic set A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$, where $T_A(x)$, $I_A(x)$, and $F_A(x)$ are real standard or nonstandard subsets of $]0^-,1^+[$. That is $T_A(x): X \to]0^-,1^+[$, $I_A(x): X \to]0^-,1^+[$, $F_A(x): X \to]0^-,1^+[$. The complement of the set A can be expressed as: $A^C = \{\langle F_A(x), 1-I_A(x), T_A(x)\rangle | x \in X\}$. Neutrosophic numbers of set A can be transformed into crisp numbers as follows:*

$$S(A) = \frac{1}{8}(T_A(x) + I_A(x) + F_A(x)) \times \left(2 + T'_A(x) - I'_A(x) - F'_A(x)\right) \tag{1}$$

Definition 2.2. [25] *A triangular nuetrosophic set in X is characterized by truth-membership function $\tilde{T}_A^L(x)$ and $\tilde{T}_A^U(x)$, indeterminacy-membership function $\tilde{I}_A^L(x)$ and $\tilde{I}_A^U(x)$, falsity-membership function $\tilde{F}_A^L(x)$ and $\tilde{F}_A^U(x)$. We simplify A to $A = \left\langle \left(T_A^L, I_A^L, F_A^L\right), \left(T_A^U, I_A^U, F_A^U\right)\right\rangle$. Let A and B be two triangular neutrosophic numbers in $X = \{x_1, x_2, \ldots, x_n\}$, the various distance measures between them are defined as following equations:*

(i) The Hamming distance

$$dH(A,B) = \frac{1}{6}\sum_{i=1}^{n} \begin{pmatrix} \left|T_A^L - T_B^L\right| + \left|T_A^U - T_B^U\right| + \left|I_A^L - I_B^L\right| \\ + \left|I_A^U - I_B^U\right| + \left|F_A^L - F_B^L\right| + \left|F_A^U - F_B^U\right| \end{pmatrix} \tag{2}$$

(ii) The Euclidean distance

$$dE(A,B) = \sqrt{\frac{1}{6}\sum_{i=1}^{n} \begin{pmatrix} \left|T_A^L - T_B^L\right|^2 + \left|T_A^U - T_B^U\right|^2 + \left|I_A^L - I_B^L\right|^2 \\ + \left|I_A^U - I_B^U\right|^2 + \left|F_A^L - F_B^L\right|^2 + \left|F_A^U - F_B^U\right|^2 \end{pmatrix}} \tag{3}$$

Definition 2.3. [26] *Let a_j $(j = 1, 2, \ldots, n)$ be a set of single valued neutrosophic number (SVNN), and then the SNWA and SNWG operators can be defined as*

$$SNWA(a_1, a_2, \ldots, a_n) = \left\langle 1 - \prod_{j=1}^{n}(1-T_j)^{w_j}, 1 - \prod_{j=1}^{n}(1-I_j)^{w_j}, \prod_{j=1}^{n}(1-F_j)^{w_j} \right\rangle \tag{4}$$

$$SNWG(a_1, a_2, \ldots, a_n) = \left\langle \prod_{j=1}^{n} T_j^{w_j}, \prod_{j=1}^{n} I_j^{w_j}, \prod_{j=1}^{n} F_j^{w_j} \right\rangle \tag{5}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of a_j $(j = 1, 2, \ldots, n)$, $\sum_{j=1}^{n} w_j = 1$.

2.2. **The best-worst method.** The BWM can simplify the comparison process and statistics of the traditional weight decision-making method [27]. DMs subjectively select the most preferred criterion and the worst criterion, and apply the pairwise comparison between these two criteria and the other criteria, which shortens the comparison process by $2n - 3$ times and reduces the complexity of the decision-making process. The specific implementation steps are clarified as below.

Step 1. Under the neutrosophic number information, set $C = \{c_1, c_2, \ldots, c_n\}$ $(n \geq 1)$ is composed of n risk evaluation criteria, and its corresponding importance weight vector is $\omega^* = (\omega_1^*, \omega_2^*, \ldots, \omega_n^*)$.

Step 2. According to the preferences of DMs, the optimal (important) criterion C_B and the worst (unimportant) criterion C_ω are determined from the criteria set C.

Step 3. Through a scoring system on a scale of 1 to 9, DMs compare the importance of the optimal criterion C_B with all other criteria, and construct a comparison vector set $C_B = \{a_{B1}, a_{B2}, \ldots, a_{Bn}\}$, where a_{Bj} represents the importance degree of C_B compared to the jth criterion.

Step 4. Similarly, construct the others-to-worst vector set $C_\omega = \{a_{1\omega}, a_{2\omega}, \ldots, a_{n\omega}\}$, where $a_{j\omega}$ is the preference of the jth criterion compared by the worst criterion C_ω.

Step 5. Establish objectives and constraints, construct a planning model and solve the set ω_j^* of optimal subjective weights as follows:

$$\begin{aligned} &\min_j \max \left\{ \left| \frac{\omega_B}{\omega_j^*} - a_{Bj} \right|, \left| \frac{\omega_j^*}{\omega_W} - a_{jW} \right| \right\} \\ &\text{s.t. } \sum_{j=1}^{n} \omega_j^* = 1,\ \omega_j^* \geq 0,\ j \in [1, n] \end{aligned} \tag{6}$$

The model can be simplified to

$$\begin{aligned} &\min \varepsilon \\ &\text{s.t. } \left| \frac{\omega_B}{\omega_j^*} - a_{Bj} \right| \leq \varepsilon, \quad \left| \frac{\omega_j^*}{\omega_W} - a_{jW} \right| \leq \varepsilon \\ &\quad \sum_{j=1}^{n} \omega_j^* = 1,\ \omega_j^* \geq 0,\ j \in [1, n] \end{aligned} \tag{7}$$

2.3. **CRITIC method.** The characteristic of CRITIC is mainly to measure the objective weight from two aspects of criteria information, one is the contrast intensity of each criterion, and the other is conflict between criteria [28]. Let $\omega' = (\omega'_1, \omega'_2, \ldots, \omega'_n)^T$, such that $\sum_{j=1}^{n} \omega'_j = 1$, $\omega'_j \geq 0$, $j \in [1, n]$ are the objective weight values of risk criteria. The set of beneficial and non-beneficial criteria is denoted by B and N. The main steps of CRITIC method are described as follows [29].

Step 1. Normalize the decision matrix by calculating the transformations performance values of criteria vectors, which can express the degree of how the alternative is close to the best performance criterion and far from the worst performance criterion.

$$\tilde{x}_{ij} = \begin{cases} \dfrac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, & j \in B \\[2ex] \dfrac{x_j^- - x_{ij}}{x_j^- - x_j^+}, & j \in N \end{cases} \tag{8}$$

where $\tilde{x}_{ij}$ represents the transformed value, x_{ij}^+ and x_{ij}^- represent the ideal value and anti-ideal value with respect to the jth criterion and ith alternative of decision matrix. If the criterion j is beneficial, then $x_j^+ = \max_i x_{ij}$, and $x_j^- = \min_i x_{ij}$. Otherwise, we have $x_j^+ = \min_i x_{ij}$ and $x_j^- = \max_i x_{ij}$.

Step 2. Determine the standard deviation σ'_j to evaluate the contrast intensity of each criterion separately for each vector x_j.

$$\sigma'_j = \sqrt{\frac{\sum_{i=1}^{m} (\tilde{x}_{ij} - \bar{x}_j)^2}{m}}, \quad \bar{x}_j = \sum_{i=1}^{m} \tilde{x}_{ij}/m \tag{9}$$

Step 3. Conduct m (the number of alternatives) symmetric matrix with dimension $m \times m$ that represents the linear correlation coefficient between x_j and $x_{j'}$, which is noted as $r'_{jj'}$.

Step 4. Calculate the conflict of criteria and obtain the information measures combined with standard deviation σ'_j according to Equation (10):

$$C'_j = \sigma'_j \sum_{j'=1}^{m} \left(1 - r'_{jj'}\right) \tag{10}$$

Step 5. Determine the objective weights of criteria according to the following equation:

$$\omega'_j = \frac{C'_j}{\sum_{j=1}^{m} C'_j} \tag{11}$$

2.4. **Extended similarity measures method.** On the basis of SNWA and SNWG operators shown in Equations (4) and (5), the similarity measures method is extended to neutrosophic environment in this section to determine the weight of each DM, which can be described as follows.

Definition 2.4. [30] *Let* $X^k = \left(a_{ij}^k\right)_{m\times n}$, $k \in [1,t]$, $i \in [1,m]$, $j \in [1,n]$ *represent the set of alternatives according to the criteria and let* $\left\langle \left(T_{11}^k, I_{11}^k, F_{11}^k\right), \left(T_{11}^{k'}, I_{11}^{k'}, F_{11}^{k'}\right)\right\rangle$ *be a basic form of triangular neutrosophic number to express the decision-making information of the first DM towards alternative* A_1. $X^k = \left(a_{ij}^k\right)_{m\times n}$ *represents the decision matrix, which can be yielded by the following equation:*

$$\begin{aligned} a_{ij}^k &= \left(a_{ij}^1, a_{ij}^2, \ldots, a_{ij}^t\right) \\ &= \left(\begin{array}{l} \left\langle 1 - \prod_{j=1}^{n}\left(1 - T_{ij}^k\right)^{W_j}, 1 - \prod_{j=1}^{n}\left(1 - I_{ij}^k\right)^{W_j}, 1 - \prod_{j=1}^{n}\left(1 - F_{ij}^k\right)^{W_j} \right\rangle, \\ \left\langle \prod_{j=1}^{n}\left(T_{ij}^{k'}\right)^{W_j}, \prod_{j=1}^{n}\left(I_{ij}^{k'}\right)^{W_j}, \prod_{j=1}^{n}\left(F_{ij}^{k'}\right)^{W_j} \right\rangle \end{array}\right) \end{aligned} \tag{12}$$

For the average matrix, it is denoted by $X^* = \left(a_{ij}^*\right)_{m\times n}$ *and the weight* W_j *for each DM is* $1/t$, *that is* $a_{ij}^* = \frac{1}{t}\sum_{k=1}^{t} a_{ij}^k$. *We can conclude that the closer the matrix* X^k *to the average matrix* X^*, *the better the weight value of the* k*th DM and hence occupy a more important role while making decisions. Thus, the similarity measures between the individual matrix and the ideal one can be expressed [31]:*

$$sm\left(X^k, X^*\right) = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n} \frac{d\left(a_{ij}^k, \left(a_{ij}^*\right)^C\right)}{d\left(a_{ij}^k, a_{ij}^*\right) + d\left(a_{ij}^k, \left(a_{ij}^*\right)^C\right)} \tag{13}$$

where

$$\begin{aligned} \left(a_{ij}^*\right) C = \Bigg(&\left\langle 1 - \prod_{j=1}^{n}\left(1 - F_{ij}^k\right)^{W_j}, \prod_{j=1}^{n}\left(1 - I_{ij}^k\right)^{W_j}, 1 - \prod_{j=1}^{n}\left(1 - T_{ij}^k\right)^{W_j} \right\rangle, \\ &\left\langle \prod_{j=1}^{n}\left(F_{ij}^{k'}\right)^{W_j}, 1 - \prod_{j=1}^{n}\left(I_{ij}^{k'}\right)^{W_j}, \prod_{j=1}^{n}\left(T_{ij}^{k'}\right)^{W_j} \right\rangle \Bigg) \end{aligned}$$

Therefore, the weight for each DM can be obtained as the following equation:

$$\lambda_k = \frac{sm\left(X^k, X^*\right)}{\sum_{k=1}^{t} sm\left(X^k, X^*\right)} \tag{14}$$

where $\lambda_k \in [0,1]$, $\sum_{k=1}^{t} \lambda_k = 1$, $k \in [1,t]$. *Through the obtained weight vector of DMs* $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_t)^T$, *all individual decision matrices can be integrated into a comprehensive decision matrix* $X = (a_{ij})_{m\times n}$ *as follows:*

$$X = [a_{ij}]_{m\times n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{array} \tag{15}$$

where

$$a_{ij} = \sum_{k=1}^{t} \lambda_k X^k = \left(\begin{array}{l} \left\langle 1 - \prod_{j=1}^{n} \left(1 - T_{ij}^{k}\right)^{\lambda_k}, 1 - \prod_{j=1}^{n} \left(1 - I_{ij}^{k}\right)^{\lambda_k}, 1 - \prod_{j=1}^{n} \left(1 - F_{ij}^{k}\right)^{\lambda_k} \right\rangle, \\ \left\langle \prod_{j=1}^{n} \left(T_{ij}^{k'}\right)^{\lambda_k}, \prod_{j=1}^{n} \left(I_{ij}^{k'}\right)^{\lambda_k}, \prod_{j=1}^{n} \left(F_{ij}^{k'}\right)^{\lambda_k} \right\rangle \end{array} \right)$$

2.5. **Prospect theory.** PT reflects the psychological factors and behavioral characteristics of DMs when faced risks in uncertain environment. It mainly replaces the utility and probability in the traditional expected utility theory through the value function and probability weight to select the optimal alternative with the highest prospect value [20]. Therefore, the prospect value V can be jointly determined by the value function $\nu(xi)$ and probability weight function $\varphi(pi)$ as follows:

$$V = \sum_{i=1}^{n} \varphi(pi)\nu(xi) \tag{16}$$

The probability weight function $\varphi(pi)$ is given by

$$\varphi(pi) = \frac{p^\gamma}{(p^\gamma + (1-p)^\gamma)^{\frac{1}{\gamma}}} \tag{17}$$

Among them, p denotes the occurrence probability of the event, and φ is the increasing function of p. γ denotes the different attitudes of DMs to treat income or risk, that is income benefit attitude coefficient and risk loss attitude coefficient.

The value function $\nu(\Delta x)$ is defined on the deviations from a reference point, which represents the behavior of the DMs and can be expressed as

$$\nu(\Delta x) = \begin{cases} \Delta x^\alpha & xi \succ \lambda \\ -\theta(\Delta x)^\beta & xi \prec \lambda \end{cases} \tag{18}$$

where Δx denotes the gain or loss, $xi \succ \lambda$ indicates that the outcome is greater than a certain reference and vice versa. α and β are the adjustable coefficient, representing the sensitivity of the DMs to risk appetite and risk aversion respectively satisfying the constraint conditions $\alpha, \beta \in (0,1)$. θ describes the risk aversion coefficient, reflecting that DMs are more sensitive to losses than gains, which satisfies $\theta > 1$. Tversky and Kahneman [20] found that when $\gamma = 0.61$, $\delta = 0.69$, $\alpha = \beta = 0.88$ and $\theta = 2.25$, the empirical results are more consistent with each other.

3. Comprehensive Evaluation Framework of the Proposed Model.

3.1. Evaluation index system for risk evaluation of SSCF. In order to better evaluate the risks of SSCF, it is necessary to identify and define potential risk sources on the basis of scientific, systematic and feasible principles. By summarizing and sorting out some of the research results on index selection and system construction of relevant risk criteria in the context of sustainability, we found that the current research mainly focuses on corporate social responsibility, economic performance, resource and environment utilization efficiency and consumption. However, the actual investigation by practitioners also shows that the sustainable operation of SC and the ability of information transmission and control in the face of risks also affect the normal development of SSCF. Therefore, based on the above analysis and actual operating conditions, this paper establishes an SSCF risk evaluation index with three levels of criteria from five dimensions, including economic performance (B1), social responsibility (B2), environmental performance (B3), sustainable supply performance (B4), and information and control capability (B5). These first-level criteria can be further divided into fourteen second-level criteria and forty-two third-level criteria, among which the third-level criteria are divided into thirty-four positive criteria (P) and eight negative criteria (N) according to their correlation with the performance ability. The specific content and expression form are shown in Table 1.

3.2. Framework of the proposed model. This research proposes an integrated BWM-CRITIC approach with PT to address the problem of SSCF risk evaluation under neutrosophic environment. This model integrates the advantages of five techniques and methods. In the case of unknown weight information of risk criteria, the combination of BWM-CRITIC method is firstly applied to calculating the subjective and objective weights of criteria. On this basis, the integrated weight for each criterion is obtained by using the uniformity entropy theory. In addition, the extended similarity measure can well reflect the relative importance differences of DMs, fuse all individual evaluation information to generate a comprehensive decision-making matrix. Finally, the PT is applied to determining the optimal alternative by measuring the distance of alternatives from reference points. The detailed process of the proposed model is as follows.

Step 1. Consider an MCGDM problem with neutrosophic information, suppose $A = (A_1, A_2, \ldots, A_m)$ $(m \geq 1)$ be a set of m alternatives, $C = \{c_1, c_2, \ldots, c_n\}$ $(n \geq 1)$ be a set of n criteria. A group of DMs are indicated by $D = \{DM_1, DM_2, \ldots, DM_k\}$ $(k \geq 1)$. On the basis of the evaluation index system, DMs use the triangular neutrosophic evaluation linguistic scale shown in Table 2 to evaluate each three-level risk criterion and different alternatives regard to criteria respectively, and then establish the corresponding neutrosophic evaluation decision-making matrix.

Step 2. Determine the subjective weights ω_j^* of risk criteria based on the BWM method (detailed in Section 2.2).

Step 3. Calculate the objective weights ω_j' of risk criteria using CRITIC method as discussed in Equations (8) to (11).

Step 4. Through the method of uniformity entropy theory [22], the subjective and objective weights of risk criteria are integrated according to the proportion of importance. The proportion η_j of the subjective weight ω_j^* in the integrated weight can be calculated as

$$\eta_j = \frac{1 - f\left(\omega_j^*\right)}{1 - f\left(\omega_j^*\right) + 1 - f\left(\omega_j'\right)} \tag{19}$$

where $f(\omega) = -\frac{1}{\log_2 p} \sum_{k=1}^{p} \omega_k \log_2 \omega_k$, indicating the uniformity of the probability distribution of the risk criteria weight vector $\omega = (\omega_1, \omega_2, \ldots, \omega_p)^{\mathrm{T}}$, $(1 \leq p \leq k)$. The larger

TABLE 1. Sustainable supply chain financial risk evaluation criteria system

Object level	First-level criteria	Second-level criteria	Third-level criteria	Category
SSCF risk evaluation criteria system	Economic performance B1	Credit status CA	Loan repayment rate CA1 Continuous operating years CA2 Transaction information risk CA3	P, P, N
		Profitability CB	Return on equity CB1 Net interest rate on total assets CB2 Return on capital CB3	P, P, P
		Solvency CC	Interest coverage ratio CC1 Asset-liability ratio CC2 Current ratio CC3	P, N, P
	Social responsibility B2	Employee rights and interests CD	Contracts and compensation CD1 Safety and health CD2 Social security and welfare CD3	P, P, P
		Brand credibility CE	ISO9001 CE1 Brand dependence CE2 Customer satisfaction CE3	P, P, P
		Public liability CF	Participation degree in philanthropy CF1 Degree of participation in public cultural construction CF2 Compliance with laws and taxes CF3	P, P, P
	Environmental performance B3	Environmental protection CG	Energy consumption level of production and operation CG1 Energy conservation and emission reduction CG2 Management measures to irresistible environmental risks CG3	N, P, P
		Resource utilization CH	Packaging recovery rate CH1 Energy resource utilization CH2 Resource handling policy CH3	P, P, P
		Environmental indicator risks CI	Discharge of wastes per unit output value CI1 Proportion of business complying with environmental permissions CI2 Business environment risk index CI3	N, P, N
	Sustainable supply performance B4	Organizational structure risks CJ	Supplier quality and stability CJ1 Order fulfillment level CJ2 Coordination of demand and supply CJ3	P, P, P
		Financial related risks CK	Financial market stability CK1 Frequency of supply chain financing CK2 Stability of collateral and accounts receivable CK3	P, P, P
		Cooperation relationship CL	Internal environment and stability of SCF CL1 Average transaction years between core companies and SMEs CL2 Litigation between subjects CL3	P, P, N
	Information and control capability B5	Information risks CM	Degree of information sharing CM1 Investment in information technology platform construction CM2 Bullwhip effect CM3	P, P, N
		Control capability CN	Response time CN1 Risk prevention and control measures CN2 Risk recovery level of supply chain CN3	N, P, P

TABLE 2. Triangular neutrosophic evaluation linguistic scale

Significance linguistic scale	Neutrosophic scale	Evaluation linguistic scale
Very Weakly Significance (VWS)	$((0.1, 0.3, 0.35), 0.1, 0.2, 0.15)$	Very Low (VL)
Weakly Significance (WS)	$((0.15, 0.25, 0.1), 0.6, 0.2, 0.3)$	Low (L)
Partially Significance (PS)	$((0.4, 0.35, 0.5), 0.6, 0.1, 0.2)$	Medium Low (ML)
Equal Significance (ES)	$((0.65, 0.6, 0.7), 0.8, 0.1, 0.1)$	Medium (M)
Strong Significance (SS)	$((0.7, 0.65, 0.8), 0.9, 0.2, 0.1)$	High (H)
Very Strongly Significance (VSS)	$((0.9, 0.85, 0.9), 0.8, 0.2, 0.2)$	Very High (VH)
Absolutely Significance (AS)	$((0.95, 0.9, 0.95), 0.9, 0.1, 0.1)$	Absolutely High (AH)

the value of $f(\omega)$, the more uniform the distribution of the weight vector. Therefore, for each risk criterion C_j, the integrated weight can be obtained as

$$\omega = \eta_j \omega_j^* + (1 - \eta_j)\omega_j' \tag{20}$$

Step 5. Calculate the weights of DMs based on the extended similarity measures as in Equations (12) to (15), and the individual decision matrices with inconsistent weights are integrated to obtain a comprehensive decision matrix.

Step 6. We apply two forms of ideal solutions as the decision-making reference points for PT, and further obtain the profit and loss values of the risk criteria as follows:

$$\begin{aligned} C_j^- &= \left(v_1^-, v_2^-, \ldots, v_n^-\right) \\ C_j^+ &= \left(v_1^+, v_2^+, \ldots, v_n^+\right) \end{aligned} \tag{21}$$

where C_j^+ and C_j^- represent the set of positive ideal solutions and negative ideal solutions of the criteria set, respectively. We can obtain the distance of criteria vector value from the positive $\left(d_{ij}^+\right)$ and negative ideal solutions $\left(d_{ij}^-\right)$ as follows:

$$\begin{aligned} d_{ij}^+ &= \sum_{j=1}^{n} d\left(v_{ij}, v_j^+\right) \\ d_{ij}^- &= \sum_{j=1}^{n} d\left(v_{ij}, v_j^-\right) \end{aligned} \tag{22}$$

where for positive criteria $v_j^+ = \max_i v_{ij}$, $v_j^- = \min_i v_{ij}$, and for negative criteria $v_j^- = \max_i v_{ij}$, $v_j^+ = \min_i v_{ij}$. We can further calculate the benefit values D^+ and cost values D^- of risk criteria as follows:

$$\begin{aligned} D^+ = \left[d_{ij}^+\right]_{m\times n} &= \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 & d_{11}^+ & d_{12}^+ & \cdots & d_{1n}^+ \\ A_2 & d_{21}^+ & d_{22}^+ & \cdots & d_{2n}^+ \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & d_{m1}^+ & d_{m2}^+ & \cdots & d_{mn}^+ \end{matrix} \\ D^- = \left[d_{ij}^-\right]_{m\times n} &= \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 & d_{11}^- & d_{12}^- & \cdots & d_{1n}^- \\ A_2 & d_{21}^- & d_{22}^- & \cdots & d_{2n}^- \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & d_{m1}^- & d_{m2}^- & \cdots & d_{mn}^- \end{matrix} \end{aligned} \tag{23}$$

Step 7. Substitute the values of D^+ and D^- into Equation (18) to determine the ideal prospect value function for decision-making alternatives as follows:

$$\nu^-\left(d_{ij}^+\right) = -\theta\left(d_{ij}^+\right)^\beta \tag{24}$$

$$\nu^+\left(d_{ij}^-\right) = \left(d_{ij}^-\right)^\alpha \tag{25}$$

Step 8. Substitute the ideal value function and the integrated risk criteria weights into Equations (16) and (17) to determine the comprehensive prospect value $\tilde{V}$ of each alternative, as shown in Equation (26) and (27).

$$\tilde{V} = \sum_{i=1}^{n} \left[\varphi^+(\omega)\nu^+\left(d_{ij}^-\right) + \varphi^-(\omega)\nu^-\left(d_{ij}^+\right)\right] \tag{26}$$

$$\varphi^+(\omega_j) = \frac{\omega^\gamma}{(\omega^\gamma + (1-\omega)^\gamma)^{1/\gamma}}, \quad \varphi^-(\omega_j) = \frac{\omega^\delta}{(\omega^\delta + (1-\omega)^\delta)^{1/\delta}} \tag{27}$$

where $\varphi^+(\omega_j)$ and $\varphi^-(\omega_j)$ denote the weight function of benefit and loss, respectively, γ and δ are coefficients of gain or loss, $\omega = (\omega_1, \omega_2, \ldots, \omega_n)$ is the integrated weight set of risk criteria. The comprehensive prospect value matrix $\tilde{V}_{ij}$ of all alternatives is represented as $\tilde{V}_{ij} = \left[\tilde{V}\right]_{m\times n}$. The larger the comprehensive prospect value of the alternative is, the more prominent its advantages are. So, we can rank the alternatives and select the best one.

4. **Numerical Application and Results.** In this section, the proposed model is applied to addressing a practical SSCF risk evaluation problem in the pharmaceutical industry. With the breakthrough and innovation of mid-to-high-end technology, the pharmaceutical industry in China has become one of the most promising and competitive industries in recent years. However, with the rapid growth of orders, some small and medium-sized enterprises are gradually affected by cash flow gaps or internal and external uncertain risk factors, which seriously damages the normal operation of the production, supply and marketing model in the SC. In view of this, initiatives to develop SSCF businesses are emerging. A large state-owned bank is seeking to find the optimal alternative to implement financing services on the basis of evaluating the SSCF risk level of relevant applicant companies. A committee of three DMs who have a long experience in pharmaceutical industry is formed to help in this evaluation. Based on the evaluation index system, they defined a set of fourteen main risk criteria (CA-CN) and forty-two sub-criteria (CA1-CN3) from five dimensions. After a primary election, three companies are shortlisted for further evaluation, denoted as $A = \{A_1, A_2, A_3\}$. The weights of risk criteria and DMs in the evaluation are unknown, expressed as $\omega = (\omega_1, \omega_2, \ldots, \omega_{42})$ and $\lambda = \{\lambda_1, \lambda_2, \lambda_3\}$. The steps applying the proposed model are described below.

Step 1. By using the neutrosophic linguistic scale, we can obtain the individual judgement preference of DMs on sub-criteria and ratings of alternatives with regard to criteria. The results of the evaluation matrix are listed in Table 3.

Step 2-Step 4. In these steps we focus on the weight acquisition of risk criteria under uncertainty. Firstly, according to the BWM method, Lingo is used to solve the planning model of Equations (6) and (7), and the subjective weight of each risk criterion is obtained as ω_j^*. Then, the objective weights ω_j' of criteria are determined by CRITIC. The integrated weights of criteria can be calculated by Equations (19) and (20), and the ratios of subjective weight and objective weight are 0.821 and 0.179, respectively. The calculation results of these weights are shown in Table 6. From Table 6, we can see that the degree of information sharing (CM1) with weight 0.0483, internal environment and stability of SCF (CL1) with weight 0.0471 and asset-liability ratio (CC2) with weight 0.0450 occupy the highest importance, which means that bank managers and relevant departments should focus on managing these risk criteria to better achieve the development of SSCF business. However, CL2 (0.0083), CF1 (0.0086) and CD1 (0.0088) are considered as the risk criteria that have the least impact to the development of SSCF.

Step 5. In order to determine the weights of DMs, Equations (12)-(15) are applied and we can obtain $\lambda_k = (0.3414, 0.3362, 0.3224)$, as shown in Table 4. These weights are then used to aggregate all individual matrices to construct a comprehensive neutrosophic decision matrix (Table 5).

Step 6-Step 8. According to Equations (21)-(27), the comprehensive prospect value matrix is calculated, and the prospect values of each alternative under different criteria are obtained as shown in Table 6. By summing up, the comprehensive prospect values of the three alternatives are $\tilde{V}_{A_1} = -1.404024568$, $\tilde{V}_{A_2} = -1.026547823$ and $\tilde{V}_{A_3} = -0.504208363$ respectively. Therefore, we can rank these alternatives as $A_3 > A_2 > A_1$, where A_3 is the optimal alternative in the decision-making process of risk assessment, which should be given priority by banks when implementing financing business.

Table 3. Neutrosophic evaluation matrix of criteria and criteria-based alternatives

	DM_1	DM_2	DM_3	DM_1			DM_2			DM_3		
				A_1	A_2	A_3	A_1	A_2	A_3	A_1	A_2	A_3
CA1	VSS	VSS	VSS	VH	AH	H	VH	AH	VH	H	VH	H
CA2	SS	ES	ES	M	M	H	ML	H	H	ML	M	H
CA3	VSS	AS	VSS	VH	VH	H	AH	VH	H	VH	H	H
CB1	SS	VSS	VSS	H	VH	H	VH	AH	H	H	VH	M
CB2	ES	ES	PS	M	H	M	ML	M	M	ML	M	ML
CB3	SS	SS	SS	M	H	VH	H	H	VH	M	H	H
CC1	VSS	SS	VSS	AH	H	VH	VH	H	VH	VH	M	H
CC2	VSS	AS	AS	AH	VH	H	AH	VH	H	AH	VH	M
CC3	SS	ES	SS	M	M	VH	M	M	H	M	M	H
CD1	PS	PS	ES	ML	M	M	M	M	H	M	M	M
CD2	SS	ES	ES	M	H	H	H	H	H	M	M	H
CD3	ES	ES	PS	ML	H	M	ML	M	M	M	M	M
CE1	SS	VSS	SS	VH	VH	AH	H	H	VH	VH	H	VH
CE2	WS	ES	ES	L	ML	ML	ML	M	M	L	M	M
CE3	ES	SS	SS	M	H	H	M	H	VH	H	H	H
CF1	WS	VWS	WS	VL	VL	L	VL	L	L	L	L	ML
CF2	ES	PS	ES	M	M	M	M	M	M	ML	M	H
CF3	ES	ES	SS	H	M	H	H	H	H	H	M	H
CG1	ES	SS	ES	H	H	VH	H	M	H	M	M	H
CG2	PS	WS	WS	L	ML	M	L	L	ML	L	ML	ML
CG3	WS	VWS	VWS	L	L	ML	L	L	M	L	ML	M
CH1	PS	PS	WS	ML	L	L	L	ML	VL	ML	ML	L
CH2	ES	ES	ES	H	ML	M	M	M	M	H	M	ML
CH3	PS	ES	ES	M	M	M	M	ML	M	M	M	M
CI1	SS	SS	ES	H	H	M	M	H	M	M	H	M
CI2	PS	WS	WS	H	ML	M	ML	ML	M	M	ML	M
CI3	ES	PS	ES	ML	M	H	ML	M	M	ML	M	H
CJ1	VSS	VSS	SS	M	VH	AH	H	VH	VH	H	VH	VH
CJ2	SS	ES	VSS	H	H	VH	H	H	H	VH	H	VH
CJ3	ES	ES	PS	M	M	H	ML	M	M	M	M	H
CK1	SS	VSS	SS	M	H	VH	H	H	H	H	H	VH
CK2	VSS	VSS	SS	M	H	VH	H	H	VH	H	VH	VH
CK3	VSS	SS	SS	H	VH	VH	H	H	AH	M	H	AH
CL1	SS	VSS	VSS	H	H	H	M	VH	H	H	VH	VH
CL2	PS	WS	ES	L	ML	H	ML	ML	M	ML	ML	M
CL3	VSS	VSS	SS	M	M	M	M	M	ML	H	M	M
CM1	VSS	AS	AS	M	VH	AH	H	VH	AH	H	H	VH
CM2	SS	ES	SS	ML	M	H	M	H	H	M	M	H
CM3	VSS	AS	SS	H	M	ML	H	M	ML	M	ML	M
CN1	SS	ES	VSS	M	M	ML	M	ML	ML	H	M	M
CN2	VSS	VSS	SS	H	H	AH	H	H	VH	VH	VH	AH
CN3	ES	ES	SS	M	M	H	H	M	H	H	M	H

Table 4. The weights of DMs

	DM_1	DM_2	DM_3
$\sum_{i=1}^{m}\sum_{j=1}^{n} d'\left(\tilde{x}_{ij}^{k}, \tilde{x}_{ij}^{*C}\right)$	1.3990	1.4019	1.3753
$\sum_{i=1}^{m}\sum_{j=1}^{n} d'\left(\tilde{x}_{ij}^{k}, \tilde{x}_{ij}^{*}\right)$	0.0999	0.01233	0.1851
$sm\left(X^k, X^*\right)$	0.00123	0.00122	0.00117
$\sum_{k=1}^{t} sm\left(X^k, X^*\right)$	0.00362	0.00362	0.00362
λ_k	0.3414	0.3362	0.3224

Table 5. The comprehensive decision-making matrix

Criteria	A_1	A_2	A_3
CA1	((0.857,0.803,0.875),0.831,0.2,0.16)	((0.937,0.886,0.937),0.866,0.125,0.125)	((0.793,0.737,0.842),0.865,0.2,0.126)
CA2	((0.501,0.449,0.58),0.662,0.1,0.158)	((0.668,0.618,0.783),0.832,0.126,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)
CA3	((0.921,0.869,0.921),0.832,0.158,0.158)	((0.857,0.803,0.875),0.831,0.2,0.16)	((0.7,0.65,0.8),0.9,0.2,0.1)
CB1	((0.793,0.737,0.842),0.865,0.2,0.126)	((0.921,0.869,0.921),0.832,0.158,0.158)	((0.685,0.635,0.772),0.866,0.16,0.1)
CB2	((0.501,0.449,0.58),0.662,0.1,0.158)	((0.668,0.618,0.739),0.833,0.127,0.1)	((0.584,0.532,0.646),0.729,0.1,0.125)
CB3	((0.668,0.618,0.738),0.832,0.126,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.857,0.803,0.875),0.831,0.2,0.16)
CC1	((0.921,0.869,0.921),0.832,0.158,0.158)	((0.685,0.635,0.772),0.866,0.16,0.1)	((0.857,0.803,0.875),0.831,0.2,0.16)
CC2	((0.95,0.9,0.95),0.9,0.1,0.1)	((0.9,0.85,0.9),0.8,0.2,0.2)	((0.685,0.635,0.772),0.866,0.16,0.1)
CC3	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.794,0.738,0.842),0.865,0.2,0.127)
CD1	((0.579,0.528,0.643),0.725,0.1,0.127)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.668,0.618,0.738),0.832,0.126,0.1)
CD2	((0.668,0.618,0.738),0.832,0.126,0.1)	((0.685,0.635,0.772),0.866,0.16,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)
CD3	((0.496,0.444,0.576),0.658,0.1,0.16)	((0.668,0.618,0.739),0.833,0.127,0.1)	((0.65,0.6,0.7),0.8,0.1,0.1)
CE1	(0.855,0.801,0.874),0.832,0.2,0.158)	((0.794,0.738,0.842),0.865,0.2,0.127)	((0.921,0.869,0.921),0.833,0.158,0.158)
CE2	((0.244,0.285,0.261),0.6,0.158,0.262)	((0.579,0.528,0.643),0.725,0.1,0.127)	((0.579,0.528,0.643),0.725,0.1,0.127)
CE3	((0.667,0.617,0.737),0.831,0.125,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.793,0.737,0.842),0.865,0.2,0.126)
CF1	((0.116,0.284,0.278),0.178,0.2,0.188)	((0.133,0.267,0.195),0.325,0.2,0.237)	((0.24,0.284,0.255),0.6,0.16,0.263)
CF2	((0.584,0.532,0.646),0.729,0.1,0.125)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.667,0.617,0.737),0.831,0.125,0.1)
CF3	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.668,0.618,0.783),0.832,0.126,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)
CG1	((0.685,0.635,0.772),0.866,0.16,0.1)	((0.668,0.618,0.739),0.833,0.127,0.1)	((0.794,0.738,0.842),0.865,0.2,0.127)
CG2	((0.15,0.25,0.1),0.6,0.2,0.3)	((0.325,0.318,0.391),0.6,0.126,0.229)	((0.501,0.449,0.58),0.662,0.1,0.158)
CG3	((0.15,0.25,0.1),0.6,0.2,0.3)	((0.24,0.284,0.255),0.6,0.16,0.263)	((0.579,0.528,0.643),0.725,0.1,0.127)
CH1	((0.325,0.318,0.391),0.6,0.126,0.229)	((0.324,0.317,0.389),0.6,0.127,0.23)	((0.134,0.267,0.193),0.328,0.2,0.238)
CH2	((0.684,0.634,0.771),0.865,0.158,0.1)	((0.579,0.528,0.643),0.725,0.1,0.127)	((0.584,0.532,0.646),0.729,0.1,0.125)
CH3	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.58,0.529,0.644),0.726,0.1,0.126)	((0.65,0.6,0.7),0.8,0.1,0.1)
CI1	((0.668,0.618,0.739),0.833,0.127,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.65,0.6,0.7),0.8,0.1,0.1)
CI2	((0.602,0.55,0.69),0.756,0.127,0.126)	((0.4,0.35,0.5),0.6,0.1,0.2)	((0.65,0.6,0.7),0.8,0.1,0.1)
CI3	((0.4,0.35,0.5),0.6,0.1,0.2)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.684,0.634,0.771),0.865,0.158,0.1)
CJ1	((0.684,0.634,0.77),0.865,0.158,0.1)	((0.9,0.85,0.9),0.8,0.2,0.2)	((0.921,0.869,0.921),0.833,0.158,0.158)
CJ2	((0.789,0.734,0.84),0.866,0.2,0.125)	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.855,0.801,0.874),0.832,0.2,0.158)
CJ3	((0.58,0.529,0.644),0.726,0.1,0.126)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.684,0.634,0.771),0.865,0.158,0.1)
CK1	((0.684,0.634,0.77),0.865,0.158,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)	((0.855,0.801,0.874),0.832,0.2,0.158)
CK2	((0.684,0.634,0.77),0.865,0.158,0.1)	((0.789,0.734,0.84),0.866,0.2,0.125)	((0.9,0.85,0.9),0.8,0.2,0.2)
CK3	((0.685,0.635,0.772),0.866,0.16,0.1)	((0.794,0.738,0.842),0.865,0.2,0.127)	((0.937,0.885,0.937),0.865,0.127,0.127)
CL1	((0.684,0.634,0.771),0.865,0.158,0.1)	((0.854,0.8,0.873),0.833,0.2,0.158)	((0.789,0.734,0.84),0.866,0.2,0.125)
CL2	((0.324,0.317,0.389),0.6,0.127,0.23)	((0.4,0.35,0.5),0.6,0.1,0.2)	((0.668,0.618,0.738),0.832,0.126,0.1)
CL3	((0.667,0.617,0.737),0.831,0.125,0.1)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.58,0.529,0.644),0.726,0.1,0.126)
CM1	((0.684,0.634,0.77),0.865,0.158,0.1)	((0.857,0.803,0.875),0.831,0.2,0.16)	((0.937,0.885,0.937),0.865,0.127,0.127)
CM2	((0.579,0.528,0.643),0.725,0.1,0.127)	((0.668,0.618,0.738),0.832,0.126,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)
CM3	((0.685,0.635,0.772),0.866,0.16,0.1)	((0.584,0.532,0.646),0.729,0.1,0.125)	((0.496,0.444,0.576),0.658,0.1,0.16)
CN1	((0.667,0.617,0.737),0.831,0.125,0.1)	((0.58,0.529,0.644),0.726,0.1,0.126)	((0.496,0.444,0.576),0.658,0.1,0.16)
CN2	((0.789,0.734,0.84),0.866,0.2,0.125)	((0.789,0.734,0.84),0.866,0.2,0.125)	((0.937,0.885,0.937),0.865,0.126,0.126)
CN3	((0.684,0.634,0.77),0.865,0.158,0.1)	((0.65,0.6,0.7),0.8,0.1,0.1)	((0.7,0.65,0.8),0.9,0.2,0.1)

This paper has proposed the PT-BWM-CRITIC to solve the SSCF risk evaluation problem with unknown information and adopted the neutrosophic set to present the DMs' preferences. On the basis of the results of the case study, we can summarize the following advantages.

1) By expressing evaluation information in the neutrosophic set, the PT-BWM-CRITIC method can maintain the integrity of SSCF risk information, and obtain more reasonable results through the prospect value of alternatives and the integrated weights of criteria.

2) Making decisions based on a multi-dimensional and multi-angle risk evaluation index system under uncertain environment can obtain more comprehensive and realistic results.

Table 6. The weight information of risk criteria and the comprehensive prospect value matrix

Criteria	Subjective weights	Objective weights	Integrated weights	A_1-Prospect value	A_2-Prospect value	A_3-Prospect value
CA1	0.0403	0.0313	0.0387	−0.00716	0.00591	−0.02127
CA2	0.0191	0.0228	0.0198	−0.06141	−0.02569	−0.01049
CA3	0.0363	0.0186	0.0331	−0.09309	−0.08267	−0.05329
CB1	0.0234	0.0356	0.0256	−0.00526	0.01465	−0.02815
CB2	0.0131	0.0302	0.0161	−0.04109	−0.00920	−0.02772
CB3	0.0201	0.0194	0.0200	−0.02589	−0.01061	0.01099
CC1	0.0346	0.0338	0.0344	0.01469	−0.03675	0.00391
CC2	0.0505	0.0197	0.0450	−0.13246	−0.12781	−0.06902
CC3	0.0147	0.0228	0.0161	−0.02167	−0.02167	0.00929
CD1	0.0058	0.0224	0.0088	−0.01711	−0.00860	−0.00406
CD2	0.0249	0.0125	0.0227	−0.02895	−0.02057	−0.01240
CD3	0.0090	0.0273	0.0122	−0.03398	−0.00649	−0.01218
CE1	0.0332	0.0252	0.0318	−0.00062	−0.01251	0.01012
CE2	0.0101	0.0275	0.0132	−0.04735	−0.00703	−0.00703
CE3	0.0130	0.0193	0.0141	−0.01927	−0.00670	0.00310
CF1	0.0050	0.0250	0.0086	−0.04160	−0.03752	−0.02168
CF2	0.0091	0.0225	0.0115	−0.02067	−0.01116	−0.00600
CF3	0.0130	0.0238	0.0149	−0.00721	−0.01994	−0.00721
CG1	0.0117	0.0336	0.0156	−0.03943	−0.03289	−0.05641
CG2	0.0068	0.0195	0.0091	−0.03606	−0.02198	−0.00535
CG3	0.0065	0.0202	0.0090	−0.04336	−0.03614	−0.00426
CH1	0.0071	0.0375	0.0125	−0.02149	−0.02161	−0.05006
CH2	0.0144	0.0405	0.0190	−0.01060	−0.03896	−0.03817
CH3	0.0136	0.0257	0.0157	−0.00973	−0.02191	−0.00973
CI1	0.0267	0.0195	0.0254	−0.04295	−0.06050	−0.03409
CI2	0.0093	0.0326	0.0135	−0.01260	−0.04424	−0.00811
CI3	0.0116	0.0367	0.0161	0.01300	−0.02722	−0.04031
CJ1	0.0332	0.0257	0.0319	−0.03491	0.01394	0.01471
CJ2	0.0436	0.0174	0.0389	−0.00506	−0.02279	0.00935
CJ3	0.0103	0.0208	0.0122	−0.02718	−0.01694	−0.00591
CK1	0.0332	0.0204	0.0309	−0.02821	−0.01774	0.01014
CK2	0.0415	0.0189	0.0374	−0.03363	−0.00455	0.02058
CK3	0.0346	0.0126	0.0306	−0.03738	−0.01166	0.01155
CL1	0.0505	0.0311	0.0471	−0.03138	0.01815	0.00207
CL2	0.0058	0.0198	0.0083	−0.03992	−0.03453	−0.00369
CL3	0.0377	0.0199	0.0345	−0.06726	−0.05706	−0.03736
CM1	0.0545	0.0199	0.0483	−0.05595	−0.00534	0.00961
CM2	0.0252	0.0215	0.0246	−0.05560	−0.03103	−0.01364
CM3	0.0483	0.0201	0.0433	−0.08478	−0.03859	−0.01244
CN1	0.0464	0.0196	0.0416	−0.07720	−0.04368	−0.01901
CN2	0.0377	0.0076	0.0323	−0.01784	−0.01784	0.00704
CN3	0.0147	0.0194	0.0155	−0.01444	−0.02709	−0.00762

3) Considering the weight of risk criterion and DM comprehensively, the computational distortion and information loss caused by the uncertainty in decision analysis process can be reduced.

4) The uniformity entropy theory can comprehensively consider the proportion of subjective and objective weights of risk criteria, and obtain the combined weights of risk criteria when the weight information is unknown.

5. Sensitivity Analysis and Comparative Analysis.

5.1. **Parameter sensitivity analysis.** Considering the different parameters involved in the process of SSCF risk evaluation, even slight changes may have a significant impact on the decision-making results. Therefore, in order to verify the stability of the proposed model and explore the influence of parameter variations on these results, two parameters are discussed in this section, including the subjective weight parameter η_j and the risk aversion coefficient θ. On the one hand, when the parameter η_j varies between 0.1 and 1 at an interval of 0.1, the changes in the comprehensive prospect value of the three alternatives are shown in Figure 1. On the other hand, we adjust the value of θ to discuss the effects of the parameters and set $\theta = [1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 3, 5, 10]$. The prospect values of the three alternatives under ten different coefficients are illustrated in Figure 2.

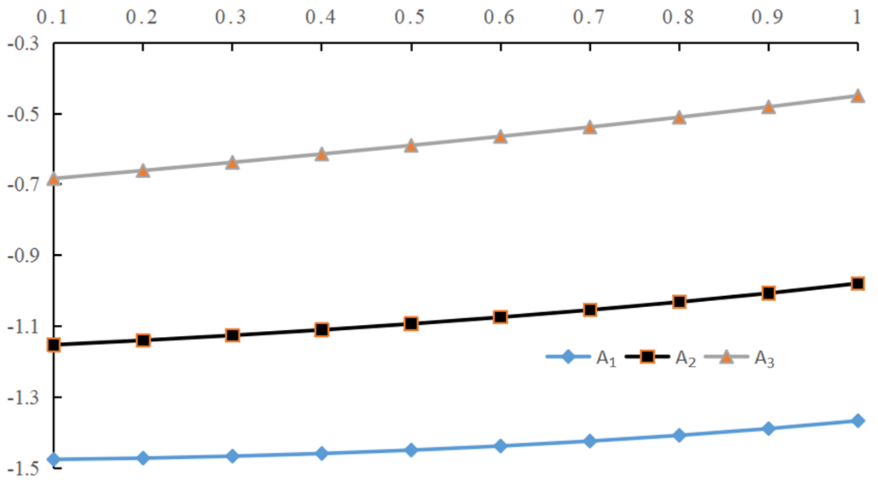

FIGURE 1. The sensitivity of comprehensive prospect value to subjective weight parameter

It is not difficult to find from Figure 1 that, with the increase of subjective weight proportion, the prospect values of the three alternatives all show an increasing trend, while the order remains unchanged, all of which are $A_3 > A_2 > A_1$. Through the risk assessment of SSCF, the results show that A_3 is the best financing enterprise, which also illustrates the stability and effectiveness of the approach proposed in this paper. When the value of θ fluctuates between 1 and 10, it can be seen from Figure 2 that the comprehensive prospect value decreases gradually from positive to negative, which also indicates that when DMs are more sensitive to risk and tend to avoid completely, the performance value of alternatives with less risk-adjusted capabilities may drop sharply. Therefore, setting a reasonable risk aversion value in the application of PT is also a key factor that DMs should consider. The ranking order of the three alternatives does not change with the increase of θ, and the optimal one is all A_3, which highlights the relative stability of the applied methods.

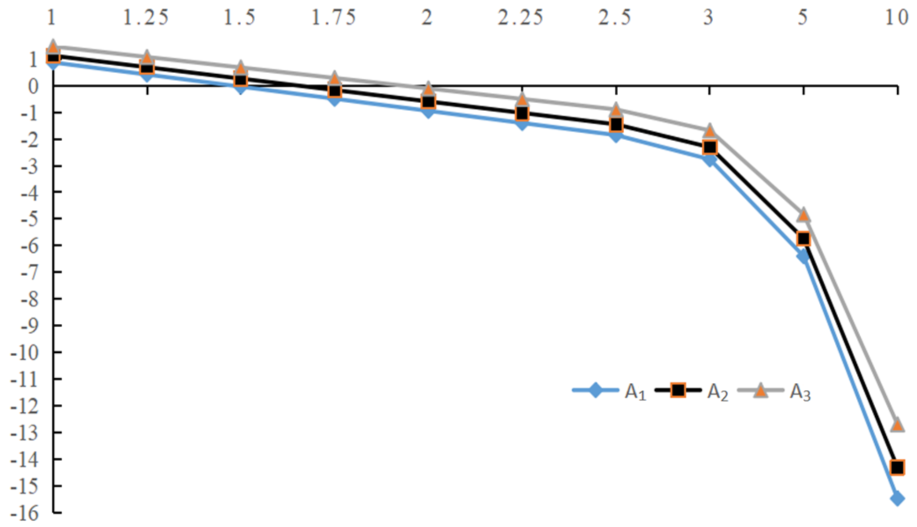

FIGURE 2. The sensitivity of comprehensive prospect value to risk aversion coefficient

5.2. **Comparative analysis.** In order to validate the effectiveness of the proposed model in evaluating the risk of SSCF, a brief comparative analysis is performed under neutrosophic environment with some representative MCGDM weighting and ranking techniques including the extended TOPSIS-VIKOR [32], the optimized maximizing deviation method-TOPSIS [33], Plithogenic VIKOR [34] and the cosine similarity measure-PT method [35]. The performance values and ranking results of alternatives under different methods are summarized in Table 7.

TABLE 7. Comparison of ranking results of different decision-making methods

Results / Methods	Performance value of A_1	Performance value of A_2	Performance value of A_3	Ranking
The extended TOPSIS-VIKOR [32]	0	1	0.5916	$A_1 > A_3 > A_2$
The optimized maximizing deviation method-TOPSIS [33]	0.6313	0.5189	0.3572	$A_1 > A_2 > A_3$
Plithogenic distance operator-VIKOR [34]	0.5	0.8698	0.4855	$A_3 > A_1 > A_2$
The cosine similarity measure method-prospect theory [35]	-1.4217	-1.0344	-0.5147	$A_3 > A_2 > A_1$
The proposed model	-1.4040	-1.0265	-0.5042	$A_3 > A_2 > A_1$

As can be observed from Table 7, the rankings and optimal alternatives obtained by different methods are generally consistent, but slightly different individually, which can be explained and analyzed by the following reasons. Firstly, the extended TOPSIS in [32] needs to obtain the weight of DM on the basis of accurately calculating the distance between the positive ideal solution and the negative ideal solution of each alternative, but ignores the relative importance of these distances to the reference point. In addition, although VIKOR can obtain a compromise solution that maximizes group utility and minimizes individual regret, it does not consider the risk sensitivity and behavioral characteristics of DMs in the face of gains and losses when making decisions, which may lead to biased decisions. Secondly, the optimized maximizing deviation method can well express the objective information of criteria, focusing on the differences in performance values of them between different alternatives. However, there are inevitable numerical differences with the objective weights calculated by CRITIC method in this paper. This ranking model adopts TOPSIS method and relies on the local evaluation unit which accurately calculates the risk criterion function, but it is easy to produce the reverse evaluation result. The plithogenic distance operator in [34] needs to integrate the degree of contradiction, degree of appurtenance and positive and negative ideal criteria on the basis of the evaluation of different criteria by each DM, which increases the complexity of decision-making. On the contrary, the acquisition of subjective risk weights in the proposed model only requires comparing the importance of the best and the worst criterion with other criteria, which involves fewer parameters and simplifies the tedious comparison process. The fourth model is consistent with the ranking result obtained in this paper, the reason lies in the use of the similarity relationship between decision matrices to determine the weights of DM in both models, and analyze the psychological factors of DMs in uncertain environment. However, the proposed methods not only can obtain reliable results, but also have stable response to the sensitivity changes of different parameters, which are more suitable for solving practical risk assessment decision-making problems.

6. **Discussions and Conclusions.** How to scientifically and reasonably carry out the risk evaluation of SSCF under uncertain information has always been the main problem restricting the stable development of participants, which is also a complex MCGDM process. Current evaluation systems are mainly based on TBL aspects; however, when considering sustainability, additional multi-dimensions criteria such as sustainable supply and information control capabilities need to be concerned. It is also worth noting that the subjective and objective weights of risk criteria and differences in the characteristics of DMs should be analyzed through appropriate decision-making techniques during the risk evaluation process. Therefore, an integrated MCGDM framework for the manipulation of uncertainty in the SSCF risk evaluation process on the basis of five-dimensions evaluation system was proposed in this paper. Firstly, we construct a neutrosophic decision-making matrix with high uncertainty consideration to integrate evaluation information. Then, on the basis of the forty-two risk criteria identified from the five main sustainability dimensions, BWM-CRITIC was applied to determining the subjective and objective weights. Additionally, the obtained relative importance of risk criteria is further integrated through the uniformity entropy theory. In this developed MCGDM model, we use an extended similarity measure to reflect the differences in inherent preferences and characteristic of DMs. Based on these weights, we manifested the PT technique in the neutrosophic environment to promote the ability of ranking the alternatives. Finally, a numerical example was given in the field of SSCF to demonstrate the proposed technique. Also, sensitivity analysis was performed to show the feasibility of the proposed technique, as well as a comparative analysis was given with existing methods to show the efficiency of the proposed model. The advantage of this paper lies in the reduction of the vagueness of DM judgments by conducting evaluation in a neutrosophic environment, considering the subjective/objective influencing factors of risk criteria and characteristic differences/psychological behavior of DMs, and highlighting the superiority of the results by comparing with other representative decision-making methods. We discuss the implications of our study for practice below.

Considering the direct and indirect impact of risk on the development of SSCF business, it is necessary to describe the characteristics of enterprises from multiple dimensions, make full use of modern financial technology enabling tools such as blockchain and big data technology to build a risk early warning platform. With the goal of sustainable development, relevant companies should conduct regular risk assessments, and avoid short-term profit improvement at the expense of damaging resources and reputation. In this case, financial institutions should also strengthen the supervision awareness of the internal structure and external environment of the entire SC. More importantly, enterprises should attach great importance to the collective interests of the SC, and provide coordination and convenience for other entities while focusing on their own development, so as to reduce the possibility of risk interference in SSCF business. Banks can also promote the commitment and trust among members, improve the social credit system, and finally achieve a win-win situation for all parties through the implementation of corresponding reward and punishment financing strategies.

The deficiency of this paper is not expressing the evaluation information of DMs from the perspective of quantitative and qualitative integration under uncertain environment. We only use the data of SSCF risk in the pharmaceutical industry to verify the effectiveness of the model. Future study will focus on the influence of hesitant and probabilistic characteristics on evaluating the expression of information in a more comprehensive way to tackle the uncertainties in the decision-making technique. In addition, other newly developed weighting methods can be applied in future research to improve the rationality and accuracy of decision-making of our proposed model. It is worth noting that the proposed approach can also be considered to solve other real-world problems from different fields, such as blockchain applicability assessment, shipping supply chain investment efficiency evaluation, and vaccine efficacy assessment.

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