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Business Risk Evaluation of Electricity Retail Company in China Using a Hybrid MCDM Method

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Abstract: Electricity retail marketization reform is in progress in China, and many electricity retail companies (ERC) have been founded. The comprehensive evaluation of business risk for ERC can help effectively manage business risk and reduce risk loss, which is vital for its healthy and sustainable development. In this paper, a new hybrid multi-criteria decision making (MCDM) method integrating the Bayesian best-worst method (BBWM) and improved matter-element extension model (IMEEM) is proposed for business risk evaluation for an ERC. The latest group MCDM method, namely the BBWM is employed to determine risk criteria weights, and the IMEEM is used to rank the business risk of ERC. The evaluation index system is built including three aspects of economic operation risk, marketable risk and political risk. The business risk of ERC in China is evaluated by using the proposed MCDM method, and the result shows the current business risk belongs to 'High' grade and closer to 'Very High' grade more. The proposed MCDM method for business risk evaluation of ERC is effective and practical, which can provide references for risk management and sustainable development of ERC.

Keywords: electricity retail company; business risk evaluation; Bayesian best-worst method; improved matter-element extension model; sustainable development

1. Introduction

Market-oriented operation is the main direction of electricity industry reform and development in the world [1,2]. In 2015, a new-round marketization reform of electricity industry was carried out in China [3], which put forward several kinds of reform, such as electricity transmission and distribution pricing, electric power market construction, electric power trading institution establishment, and electricity retail side deregulation [2,4,5]. With the deepening of marketization reform of the electricity industry, the business models of electricity generation side, electricity transmission & distribution side, and electricity retail side will change largely. Here, the marketization reform of electricity retail side has attracted increasing attention from academics and practitioners [6–9]. In China, the electricity retail business has been separated from the utility company to becomes the core business of electricity retail company. Currently, the electricity retail company can be incorporated by social capital holders and other investors in China, which will improve the competitiveness of electricity retail market. The diversified demands of electricity customers push electricity retail companies to enhance the business performance, such as improving electricity retail service quality and providing energy conservation advices. Meanwhile, the related policies such as 'Administrative measures for access and exit of electricity retail company' and 'Administrative measures for order release of distribution network business' have put forward new requirement for electricity retail company. Both the internal operation and external policy have posed certain business risks to electricity retail companies.

In China, the electricity retail pricing model is changing from the government regulation to market competition (deregulation) [10]. Currently, due to the marketization reform of electricity industry in China, there are hundreds of electricity retail companies to be found in many provinces of China, such as Guangdong, Chongqing, Zhejiang, Shanxi, et al. It can be said that the electricity retail market is competitive [6,11]. The core business of electricity retail companies is selling electricity at a certain price, which will face risks from internal operation and external policy. Therefore, under the current situation of marketization reform of the electricity industry, it is very important to evaluate the business risk of electricity retail companies, which can provide references for the risk management of electricity retail companies and promote sustainable development.

Currently, there are some studies focusing on the risk management of electricity retail company. Boroumand and Zachmann stated the risk exposure level of an electricity retailer is unclear ex ante owing to the structural dimensions of electricity market risks, and then proposed that pure portfolios of contracts are incomplete risk management instruments under current market situation [12]. Conejo and Carrion proposed a risk-constrained electricity procurement the method for a large consumer, which aims to minimize the electricity procurement cost while limiting the electricity cost fluctuation risk related to the electricity pool price volatility [13]. Ahmadi et al. proposed a risk-constrained optimal strategy model for electricity retailers which considers the financial risk of market price uncertainty as a constraint in the stochastic framework, and Benders decomposition algorithm was employed to solve the model [14]. Zare et al. proposed a risk-based electricity procurement model for large consumers, which considers the risk preference of large consumers and uncertainties related to pool price and expected procurement cost by using information gap decision theory, and the electricity procurement decision was evaluated by two criteria including the robustness of decision against experiencing high procurement costs and the opportunity of taking advantage of low procurement costs [15]. Kharrati et al. proposed an equilibrium model for electricity retailer's medium-term decision making, which modelled consumer's retail choice behavior with an econometric model and employed Conditional Value at Risk (CVaR) to tackle retailer's risk caused by rivals' strategy, and the Lagrangian relaxation method and Nash equilibrium point of the competitive retailers were used to solve this model [16]. Deng et al. proposed a real-time pricing model for industrial, residential, and commercial consumers by electricity retailers with the consideration of uncertainties. including renewable energy generation, electricity demand, and pool market price modelled as risks, and risk-averse and risk-neutral strategies of electricity retailer were also proposed for electricity procurement issues [17]. Bartelj et al. studied the influence of stochastic parameters including electricity demand and wholesale market price volatility on the retailer's overall risk exposure, and modelled for consumer demand, electricity spot price, and forward price curve were proposed for risk-premium determination [18]. Hatami et al. proposed an optimal selling price and energy procurement strategy method for electricity retailer using mixed-integer stochastic programming technique, and the risks were also considered which were modelled by conditional value-at-risk methodology [19]. Imani et al. studied the strategic behaviors of electricity retailers who maximize their profit and minimize their risk, and modelled risk management issue of retailer companies by using bi-level programming method as a Mixed Integer programming (MIP) problem, which can be efficiently solved by employing available commercial solvers [20].

According to the current research, there are some studies addressing the risk management of electricity retail company, mainly focusing on electricity retail company decision making with the consideration of risk related to uncertainties by using different models and methods, and the economic operation risk of electricity retail company is also valued by employing CVaR or other methods. The current research has provided valuable references for this paper. However, the current research only considers economic operation risk related to the business of electricity retail companies. In fact, there are several aspects of potential risks related to the business of electricity retail companies, such as economic operation risk deduced by uncertainties, marketable risk produced by competitors, and political risk caused by policy formulation and implementation. Therefore, different aspects of risks represented by multiple risk criteria should be considered for the effective and practical decision making of electricity retail company. In this paper, the business risk of electricity retail company is analyzed and evaluated with the consideration of different sources of risks such as economic operation, marketable and political risks. The business risk evaluation index system for electricity retail company is built including multiple risk criteria. Meanwhile, considering multiple risk criteria, a new hybrid multi-criteria decision making (MCDM) technique is proposed for the business risk evaluation of electricity retail company.

One contribution of this paper is to provide a new view for business risk evaluation of electricity retail company, which not only focuses on economic operation risk, but also considers marketable risk and political risk. Current studies in this field mainly focus on economic operation risk, so it can be said this paper extends the business risk scope of electricity retail company which considers multiple sources of risks related to electricity retail company business. Another contribution of this paper is to propose a new hybrid MCDM method for business risk evaluation of electricity retail company, which combines Bayesian best worst method (BBWM) and improved matter-element extension model. Of which, the BBWM is used to determine the weights of business risk criteria which can consider the preferences and opinions of multiple decision makers, and the improved matter-element extension model is employed to rank the overall business risk level of electricity retail company. The BBWM is the latest group MCDM method proposed in 2019, which is an extension of BWM [21,22]. Different from the BWM which can only consider the opinion and judgement of one decision maker, the BBWM can consider different preferences of multiple decision makers by using probability distributions method [23]. Therefore, the BBWM method is used to determine the weights of different risk criteria based on the preferences of multiple decision makers in this paper. Meanwhile, the improved matter-element extension model is employed to rank the overall business risk level of electricity retail company, which the rule of maximum membership degree of original matter-element extension model [24,25] is modified and improved by the rule of proximity degree. Compared with the original matter-element extension model, the improved matter-element extension model is more appropriate and effective for business risk evaluation of electricity retail company [26]. Currently, the business risk of electricity retail companies has been rarely evaluated comprehensively. This paper conducts the comprehensive evaluation on business risk of electricity retail company with the consideration of economic operation risk, marketable risk and political risk, which can fill this research gap. Meanwhile, the BBWM and improved matter-element extension model are to be used the first time for risk management of electricity companies, extending the application domains of BBWM and matter-element extension model.

The rest of this paper is structured as follows. Section 2 introduces the basic theory of the proposed MDCM method including the BBWM and improved matter-element extension model for the business risk evaluation of electricity retail company. The business risk evaluation index system for electricity retail company is built in Section 3. The empirical analysis is conducted in Section 4, and discussion is performed in Section 5. Section 6 concludes this paper.

2. Basic Theory of the Proposed MCDM Method for Business Risk Evaluation of Electricity Retail Company

In this paper, the business risk of electricity retail companies is comprehensively evaluated with the consideration of multiple risk criteria, including economic operation risk, marketable risk, and political risk. In fact, some criteria of electricity retail company may hold high risk, while other criteria have low risk. So, different risk criteria may be conflicting, which need to be comprehensively considered. The MCDM method is a decision-making method which can consider multiple and conflicting criteria. In this paper, a new hybrid MCDM method is proposed for the business risk evaluation of electricity retail companies, which includes the BBWM and improved matter-element extension model. The BBWM is used to determine the weights of multiple risk criteria, and the improved matter-element extension model is utilized to rank the overall business risk level of electricity retail companies. The detailed backgrounds of these two methods are introduced in the followings.

2.1. The BBWM for Weight Determination of Evaluation Criteria

The BBWM is an extension of BWM, which can consider different preferences and opinions of multiple decision makers [23]. The BWM was proposed in 2015, which is a new pairwise comparison-based MCDM method [21]. Compared with the popular and widely-used pairwise comparison-based MCDM method AHP which needs $n(n-1)/2$ pairwise comparisons, the BMW only need $2n-3$ pairwise comparisons, which can largely reduce the frequency of pairwise comparisons [27,28]. Different from the AHP, the decision-maker only need to select the best and worst criteria, and then conducts comparisons between them and other criteria in the BWM. This reduced frequency of pairwise comparisons in the BWM compared with the AHP can aid decision-makers to provide more reliable comparisons among different criteria [22,29,30]. The detailed steps of the BWM for criteria weights determination are elaborated as follows.

Step 1: Build the evaluation index system including a set of decision-making criteria. The evaluation index system needs to be firstly built including multiple criteria, which can embody the performances of alternatives from different perspectives. Suppose there are n criteria $\{c_1, c_2, \cdots, c_n\}$ for the evaluation index system.

Step 2: Identify the best criterion represented by c_B and the worst criterion represented by c_W from all the evaluation criteria. In this step, one decision maker needs to select the best criterion c_B and the worst criterion c_W according to his/her preference and judgement. The best criterion c_B is the most significate criterion among all the criteria, and the worst criterion c_W is the least significate criterion compared with other criteria in the evaluation index system.

Step 3: Conduct pairwise comparisons between the best criterion and all the criteria in the evaluation index system. The decision-maker calibrates his/her preference and subjective judgement for the best criterion compared with all other criteria in the evaluation index system, which can be expressed by an integer in the interval of [1,9]. The larger the integer value, the more important the best criterion compared to other criteria. After the decision maker conducts the pairwise comparisons between the best criterion selected from the evaluation index system and other criteria, it can obtain the 'Best-to-Others' vector A_B, which is:

$$A_B = (a_{B1}, a_{B2}, \cdots, a_{Bn}) \tag{1}$$

where $a_{Bj}(j = 1, 2, \cdots, n)$ stands for the significance of the best criterion c_B to criterion c_j.

Step 4: Conduct pairwise comparisons between all the criteria and the worst criterion selected from the evaluation index system. The decision-maker calibrates his/her preferences and subjective judgement for the worst criterion compared with all other criteria in the decision-making index system, which can be expressed by an integer in the interval of [1,9]. The larger the integer value, the more important the criterion compared to the worst criterion. After the decision maker conducts the pairwise comparisons between the worst criterion selected from the evaluation index system and all other criteria, it can obtain the 'Others-to-Worst' vector A_W, which is:

$$A_W = (a_{1W}, a_{2W}, \cdots, a_{nW}) \tag{2}$$

where $a_{jW}(j = 1, 2, \cdots, n)$ stands for the significance of criterion c_j to the worst criterion c_W.

Step 5: Calculate the optimal weights $\left(w_1^*, w_2^*, \cdots, w_n^*\right)$ of all the evaluation criteria. According to the criteria weight determination rule of the BWM, the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ needs to be minimized, namely:

$$
\begin{aligned}
&\min_j \max\left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right|\right\} \\
&s.t.\begin{cases} \sum\limits_{j=1}^{n} w_j = 1 \\ w_j \geq 0, j = 1, 2, \cdots, n \end{cases}
\end{aligned}
\tag{3}
$$

Equation (3) can also be transformed to Equation (4), and then the optimal weights of all the evaluation criteria can be obtained.

$$
\begin{aligned}
&\min \xi \\
&s.t.\begin{cases} \left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \\ \left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi \\ \sum\limits_{j=1}^{n} w_j = 1 \\ w_j \geq 0, j = 1, 2, \cdots, n \end{cases}
\end{aligned}
\tag{4}
$$

Although the BWM has some merits, it can only determine the weights of different decision-making criteria according to the subjective judgement of only one decision-maker, which cannot consider multiple decision-makers at one time. If there are several decision-makers to give preferences and judgements, the BWM needs to be used several times, and each time is only for one decision-maker. The weights of different decision-making criteria in multiple decision-makers case can be finally calculated by using arithmetic or geometric mean operator method, which average different weights of criteria obtained from different decision-makers by using the BWM. However, this mean operator method for multiple decision-makers case has drawbacks such as outlier sensitivity and restricted information provision. In fact, the best criteria and worst criteria are selected by different decision-makers are usually different, and the pairwise comparisons between two criteria are also different. Therefore, when the BWM is used to determine the weights of different decision-making criteria, considering the fact that there are usually multiple decision makers, the BWM needs to be extended to group decision-making environment, namely considering the preferences and judgements of multiple decision makers at one time. In 2019, a new group MCDM method named Bayesian best-worst method (BBWM) was proposed by researchers Mohammadi and Rezaei [23], which can weight different decision-making criteria in the case of multiple decision-makers at one time, rather than the mean operator method. For the detailed computation, the BWM and BBWM have similar inputs, namely the 'Best-to-Others' vector A_B and 'Others-to-Worst' vector A_W, but the output of the BBWM is more than that of the BWM, not only includes the optimal aggregated weights of different evaluation criteria which comprehensively consider the preferences and subjective judgements of different decision-makers, but also includes the confidence levels of the weighting results of different criteria.

For the BBWM, there are probabilistic interpretations for the inputs and outputs. From the perspective of probability, the evaluation criterion in the evaluation index system can be treated as a random event, and then the optimal weight of evaluation criteria weights can be treated as its occurrence likelihoods. Therefore, after the the 'Best-to-Others' vector A_B and 'Others-to-Worst' vector A_W are determined, they are conducted as probability distributions with multinomial distribution, and the outputs are also conducted as probability distributions with multinomial distribution. The probability mass function for the multinomial distribution related to the worst criterion A_W is:

$$P(A_W|w) = \frac{(\sum_{j=1}^{n} a_{jW})!}{\prod_{j=1}^{n} a_{jW}!} \prod_{j=1}^{n} w_j^{a_{jW}} \tag{5}$$

where w stands for the probability distribution.

The probability of event j is proportionate to the frequency of event occurrence to the total frequency of trials according to multinomial distribution, namely:

$$w_j \alpha \frac{a_{jW}}{\sum_{j=1}^{n} a_{jW}} \tag{6}$$

Then, it can be obtained:

$$\frac{w_j}{w_W} \alpha a_{jW} \tag{7}$$

Meanwhile, the best criterion A_B can also be modeled by employing multinomial distribution. It should be known that the modelling for the best criterion A_B is different from that of the worst criterion A_W because there is totally reverse for the pairwise comparisons between the best criterion A_B with all other criteria and the worst criterion A_W with all other criteria, namely:

$$A_B \alpha multinomial(1/w) \tag{8}$$

where/stands for the element-wise division operator.

Then, it can be obtained as:

$$\frac{w_B}{w_j} \alpha a_{Bj} \tag{9}$$

Therefore, the weights determination of all the evaluation criteria in the BWM is transformed to the probability distribution estimation. In the BBWM, the statistical inference technique is used for determining w in the multinomial distribution. Currently, the maximum likelihood estimation method has been arguably the most popular inference technique which is employed in the BBWM. Meanwhile, the Dirichlet distribution is used to weight all the decision-making criteria in the Bayesian inference. However, the maximum likelihood estimation inference including both A_B and A_W is hard to solve due to the complexity, and the simple Dirichlet-multinomial conjugate is failure to encompass both A_B and A_W. Under this consideration, a Bayesian hierarchical model is required to be built [23].

Suppose there are n criteria evaluated by k decision-makers using vectors A_B^k and A_W^k. The optimal weight of evaluation criteria is represented by w^{agg}, which can be obtained according to the optimal weights w^k of evaluation criteria deduced from k decision-makers. $A_B^{1:k}$ and $A_W^{1:k}$ are known in the BBWM, but it needs to calculate $w^{1:k}$ and w^{agg}. The joint probability distribution can be obtained as:

$$P(w^{agg}, w^{1:k} \middle| A_B^{1:k}, A_W^{1:k}) \tag{10}$$

Then, the probability of each individual variable can be caluculated by utilizing the following probability rule:

$$P(x) = \sum_{y} P(x, y) \tag{11}$$

where x and y are respectively arbitrary random variables.

The development of the Bayesian hierarchical model in the BBWM follows Ref. [23]. The Markov-chain Monte Carlo method is utilized to determine the posterior distribution of Bayesian hierarchical model. Compared with the BWM, the optimization problems represented by Equations (3) and (4) are replaced by the probabilistic model in the BBWM. In the meantime, the credal orderings of evaluation criteria weights are also introduced, and interested readers can consult Ref. [23].

2.2. Improved Matter-Element Extension Model for Business Risk Ranking

Matter-element extension model proposed by Cai et al. in 1983, which combines the matter-element theory and extension set theory, is to evaluate the research object and determine the comprehensive evaluation level according to the correlation degrees between the research object and different evaluation levels pre-set in this model [24,31,32]. In this model, the object can be characterized by the basic element (also named as matter-element), which can be represented by an ordered triple $R = (P, c, v)$. Object in the name of P, characteristics c, and value v are three elements of matter-element R.

Suppose object P can be described by n characteristics $C_1, C_2, \ldots, C_n$ and the corresponding values $v_1, v_2, \ldots, v_n$. Then, the matter-element R can be called as n-dimensional matter-element, denoted as:

$$R = (P, C, v) = \begin{bmatrix} P & C_1 & v_1 \\ & C_2 & v_2 \\ & \cdots & \cdots \\ & C_n & v_n \end{bmatrix} \tag{12}$$

where $C = [C_1, C_2, \cdots, C_n]^T$ represents characteristics, namely evaluation criteria, $v = [v_1, v_2, \cdots, v_n]^T$ is the corresponding values of C.

The basic theory of the original matter-element extension model can refer to [25,31,33,34]. It can be seen that the original matter-element extension model is to evaluate the objective by calculating correlation degrees between the objective and different evaluation grades. With respect to the algorithm, the correlation degree can be regarded as the extension of degree of membership in fuzzy mathematics. Therefore, the evaluation rule of matter-element extension model can be considered as the maximum membership degree rule [24]. However, this rule cannot accurately reflect the fuzziness of the evaluated objective and is easy to loss evaluation information in some cases, which will lead to the biased and improper evaluation result [26,35]. Therefore, in order to tackle this issue, the evaluation rule of the original matter-element extension model should be improved. In this paper, the proximity degree is employed to substitute for the correlation degrees. The detail steps of improved matter-element extension model are introduced as bellows.

Step 1: Set the matter-element in classical field and matter-element in controlled field.

Set the matter-element in classical field R_j as:

$$R_j = (P_j, C_i, v_{ij}) = \begin{bmatrix} P_j & C_1 & v_{1j} \\ & C_2 & v_{2j} \\ & \cdots & \cdots \\ & C_n & v_{nj} \end{bmatrix} = \begin{bmatrix} P_j & C_1 & \langle a_{1j}, b_{1j} \rangle \\ & C_2 & \langle a_{2j}, b_{2j} \rangle \\ & \cdots & \cdots \\ & C_n & \langle a_{nj}, b_{nj} \rangle \end{bmatrix} \tag{13}$$

where P_j represents the jth evaluation grade; C_i represents characteristics of P_j, which are the evaluation criteria; v_{ij} represents the corresponding value of P_j related to C_i, which is interval range, namely $v_{ij} = \langle a_{ij}, b_{ij} \rangle (i = 1, 2, \cdots, n)$; and a_{ij}, b_{ij} are respectively upper boundary and lower boundary of v_{ij}.

Set the matter-element in controlled field R_p as:

$$R_p = (P, C_i, v_{ip}) = \begin{bmatrix} P & C_1 & v_{1p} \\ & C_2 & v_{2p} \\ & \cdots & \cdots \\ & C_n & v_{np} \end{bmatrix} = \begin{bmatrix} P & C_1 & \langle a_{1p}, b_{1p} \rangle \\ & C_2 & \langle a_{2p}, b_{2p} \rangle \\ & \cdots & \cdots \\ & C_n & \langle a_{np}, b_{np} \rangle \end{bmatrix} \tag{14}$$

where P represents all the evaluation grades, v_{ip} represents the value range of P related to C_i,$v_{ip} = \langle a_{ip}, b_{ip} \rangle (i = 1, 2, \cdots, n)$, and a_{ip}, b_{ip} are respectively upper boundary and lower boundary of v_{ip}.

Step2: Set the matter-element to be evaluated.

Set the matter-element to be evaluated R_0 as:

$$R_0 = (P_0, C_i, v_i) = \begin{bmatrix} P_0 & C_1 & v_1 \\ & C_2 & v_2 \\ & \cdots & \cdots \\ & C_n & v_n \end{bmatrix} \tag{15}$$

where v_i is the value of C_i for the matter-element to be evaluated.

Step 3: Determine the weights of criteria

The weights of criteria are important for the comprehensive evaluation on the matter-element to be evaluated, which need to use appropriate method. In this paper, the BBWM is employed to determine the weights of all risk criteria.

Step 4: Calculate the proximity degrees of the matter-element to be evaluated for different evaluation grades.

The theoretical analysis, substituting the proximity degree for the correlation degrees, has been conducted in Ref. [36], and the proximity degree function was proposed as:

$$N = 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} D w_i \tag{16}$$

where N is the proximity degree, D is the distance, and w_i is the weights of the ith criteria, which can be obtained using the BBWM.

According to Equation (16), the proximity degrees of the matter-element to be evaluated for different evaluation grades can be calculated according to Equation (17).

$$N_j(p_0) = 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} D_j(v_i) w_i \tag{17}$$

where $N_j(p_0)$ is the proximity degree of the matter-element to be evaluated for the jth evaluation grade, $D_j(v_i)$ is the distance of the matter-element to be evaluated from the matter-element in classical field, $D_j(v_i) = \left| v_i - \frac{a_{ij}+b_{ij}}{2} \right| - \frac{1}{2}(b_{ij} - a_{ij})$, n is the number of evaluation criteria.

Step 5: Rank.

According to the calculation results of the proximity degrees of the matter-element to be evaluated for different evaluation grades, it can be obtained that the matter-element to be evaluated is belonged to the j'th evaluation grade according to Equation (18).

$$N_{j'}(p_0) = \max\left\{ N_j(p_0) \right\} \tag{18}$$

Suppose

$$\overline{N}_j(p_0) = \frac{N_j(p_0) - \min\limits_j N_j(p_0)}{\max\limits_j N_j(p_0) - \min\limits_j N_j(p_0)} \tag{19}$$

where $\overline{N}_j(p_0)$ represents the standardized proximity degree of the matter-element to be evaluated for the jth evaluation grade, $\min_j N_j(p_0)$ represents the minimum of proximity degrees in all evaluation grades, $\max_j N_j(p_0)$ represents the maximum of proximity degrees in all evaluation grades.

$$j^* = \frac{\sum_{j=1}^{m} j\overline{N}_j(p_0)}{\sum_{j=1}^{m} \overline{N}_j(p_0)} \tag{20}$$

where j^* is the variable eigenvalue of the matter-element to be evaluated.

The attributive degree of the matter-element to be evaluated tending to adjacent evaluation grades can be judged according to j^*.

In this paper, a new hybrid MCDM method for business risk evaluation of electricity retail company is proposed which combines the BBWM and improved matter-element extension model. The BBWM is used to determine the weights of business risk evaluation criteria which can consider the preferences and opinions of multiple decision makers, and the improved matter-element extension model is employed to rank the overall business risk grade of electricity retail company. The BBWM is the latest group MCDM method and shows priority over BWM, which considers different preferences of multiple decision makers by using the probability distributions method. The weight determination for risk criteria by using the BBWM is more practical and credible. The improved matter-element extension model is employed to rank the overall business risk grade of electricity retail companies, whereby the rule of maximum membership degree of the original matter-element extension model is modified and improved by the rule of proximity degree. The ranking result by using the improved matter-element extension model is more effective and appropriate.

The procedure of the proposed MCDM method for business risk evaluation of electricity retail companies in this paper is elaborated in Figure 1.

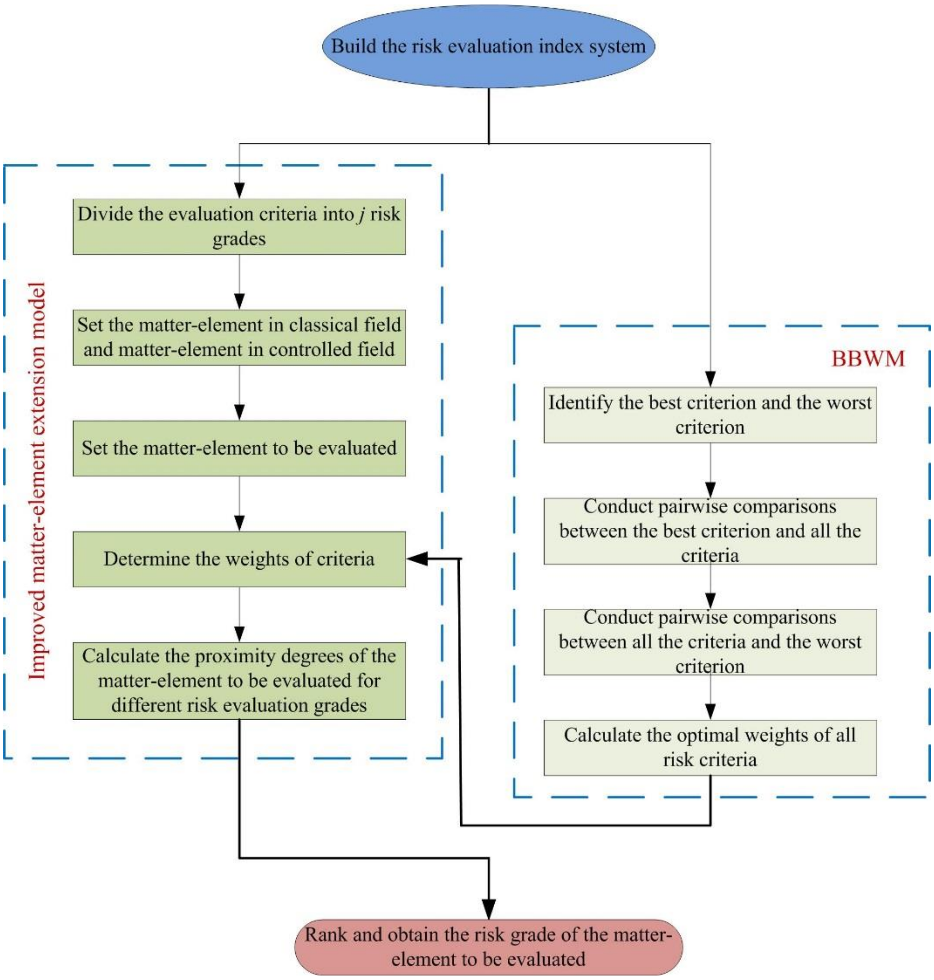

Figure 1. The procedure of the proposed MCDM method for business risk evaluation of electricity retail company.

3. Evaluation Index System for Business Risk Evaluation of Electricity Retail Company

The evaluation index system is important for the business risk evaluation of electricity retail companies. The representative and significant criteria should be included in the evaluation index system, which can reflect the main characteristics and connotations of business risk of electricity retail company. In this paper, the evaluation index system of business risk evaluation of electricity retail companies is built not only including economic operation risk, but also considering marketable risk and political risk. Moreover, these three risk criteria respectively include several sub-criteria. The detailed determination process for evaluation index system of business risk evaluation of electricity retail company is as follows:

Firstly, the initial sub-criteria for economic operation risk criterion, marketable risk criterion, and political risk criterion are determined according to the related industrial reports and academic literature. Secondly, the experts including academic professors and enterprise practitioners in the fields of enterprise risk management and electric power industry management are invited to review the initial selected risk sub-criteria, and then screen more important risk sub-criteria related to economic operation risk criterion, marketable risk criterion and political risk criterion based on their professional knowledge and practical experience. Finally, the less important risk sub-criteria are deleted according to comments from invited experts, and then the final risk sub-criteria are determined for business risk evaluation of electricity retail company.

The evaluation index system for business risk evaluation of electricity retail company is shown in Figure 2, which includes three risk criteria and eight risk sub-criteria.

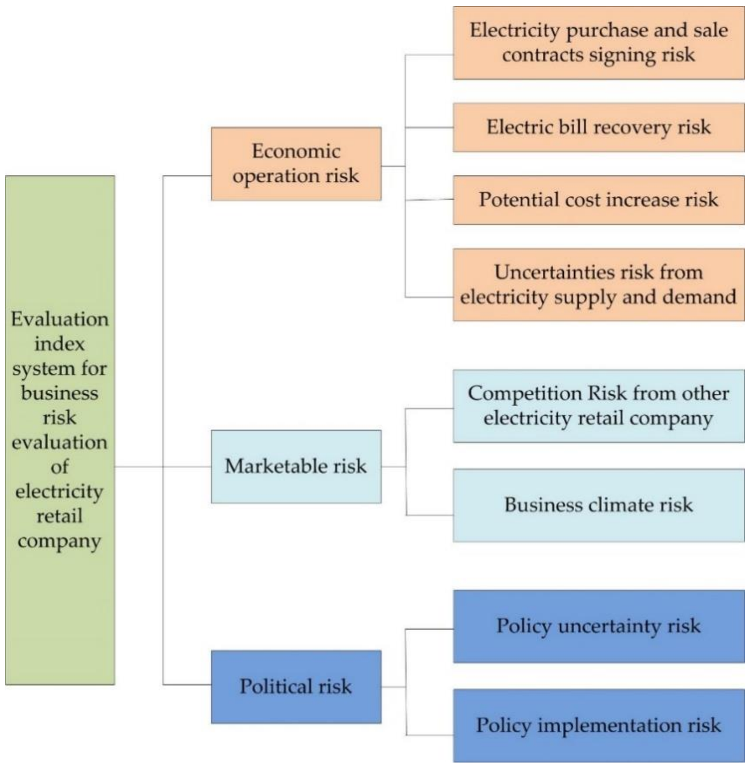

Figure 2. Evaluation index system for business risk evaluation of electricity retail company.

Economic operation risk criterion includes electricity purchase and sale contracts signing risk sub-criterion (C1) [37,38], electric bill recovery risk sub-criterion (C2) [39,40], potential cost increase risk sub-criterion (C3) [41], and uncertainties risk from electricity supply and demand sub-criterion (C4) [42,43]. Electricity purchase and sale contracts signing risk is mainly caused by the invalid or rescinded contracts signed with the electricity generation company and consumers due to the inappropriate process and operation. Electric bill recovery risk is mainly caused by the consumers who are unable to pay the electric bill terminally and timely. Potential cost increase risk is mainly caused by the fluctuant price and unanticipated natural hazard. Uncertainties risk from electricity supply and demand is mainly caused by the fluctuation of electricity price and supply of electricity generation company and electricity demand of consumers.

For marketable risk criterion, it includes competition risk from other electricity retail company sub-criterion (C5) [44,45] and business climate risk sub-criterion (C6) [46]. In China, the electricity retail company can be founded by several investors, such as electricity generation company, energy management service company, IT company and utilities. So, the electricity selling market is competitive. One electricity retail company will face competitors and face risk from other electricity retail companies. Business climate risk is mainly caused by the complicated and tedious procedures of acceptance and the transactions in the electricity selling business with the characteristics of long handling time and non-transparent information.

For political risk criterion, it includes policy uncertainty risk sub-criterion (C7) [47,48] and policy implementation risk sub-criterion (C8) [49,50]. In China, a new round of marketization reform of electricity industry is in progress, and many policies have been promulgated and implemented [2,51–53]. With the deepen of China's electricity marketization reform, the new policies related to electricity retail market will be further issued and amended focusing on admittance standard, subject identity, involvement qualification, pricing, regulation of electricity retail company, which will bring impacts on the business operation of electricity retail company. Currently, there are mainly two policies related to electricity retail in China since 2015, namely 'Administrative measures for access and exit of electricity retail company' and 'Administrative measures for order release of distribution network business'.

Some measures of these two policies are inconsistent with other electric power policies such as the 'Electricity Act', thus there are certain risks to be faced electricity retail companies when obeying these two policies.

4. Empirical Analysis

In this section, the empirical analysis is conducted to rank business risk of electricity retail company and determine the risk level by employing the proposed MCDM model combining the BBWM and improved matter-element extension model. In this paper, the business risk of electricity retail companies in China is the matter-element to be evaluated, which is divided into five grades, namely very low (VL), low (L), medium (M), high (H), and very high (VH).

4.1. Set the Matter-Element in Classical Field and Matter-Element in Controlled Field

Because there are five business risk grades for electricity retail company, it can be obtained that the matter-elements in classical field are R_1, R_2, R_3, R_4, and R_5. Then, there are P_1, P_2, P_3, P_4, and P_5. Here, P_1 represents very low business risk, P_2 represents low business risk, P_3 represents medium business risk, P_4 represents high business risk, and P_5 represents very high business risk.

According to the evaluation index system of business risk of electricity retail company showed in Figure 2, all eight risk sub-criteria are qualitative indices. In this paper, a scoring system with a 10-point scale is devised, and the sub-criteria values of the matter-elements in classical field R_1, R_2, R_3, R_4, and R_5 are respectively 0–2, 2–4, 4–6, 6–8, and 8–10 successively. Then, the matter-elements in classical field are:

$$R_1 = \begin{bmatrix} P_1 & C1 & \langle 0,2\rangle \\ & C2 & \langle 0,2\rangle \\ & C3 & \langle 0,2\rangle \\ & C4 & \langle 0,2\rangle \\ & C5 & \langle 0,2\rangle \\ & C6 & \langle 0,2\rangle \\ & C7 & \langle 0,2\rangle \\ & C8 & \langle 0,2\rangle \end{bmatrix};\ R_2 = \begin{bmatrix} P_2 & C1 & \langle 2,4\rangle \\ & C2 & \langle 2,4\rangle \\ & C3 & \langle 2,4\rangle \\ & C4 & \langle 2,4\rangle \\ & C5 & \langle 2,4\rangle \\ & C6 & \langle 2,4\rangle \\ & C7 & \langle 2,4\rangle \\ & C8 & \langle 2,4\rangle \end{bmatrix};\ R_3 = \begin{bmatrix} P_3 & C1 & \langle 4,6\rangle \\ & C2 & \langle 4,6\rangle \\ & C3 & \langle 4,6\rangle \\ & C4 & \langle 4,6\rangle \\ & C5 & \langle 4,6\rangle \\ & C6 & \langle 4,6\rangle \\ & C7 & \langle 4,6\rangle \\ & C8 & \langle 4,6\rangle \end{bmatrix};$$

$$R_4 = \begin{bmatrix} P_4 & C1 & \langle 6,8\rangle \\ & C2 & \langle 6,8\rangle \\ & C3 & \langle 6,8\rangle \\ & C4 & \langle 6,8\rangle \\ & C5 & \langle 6,8\rangle \\ & C6 & \langle 6,8\rangle \\ & C7 & \langle 6,8\rangle \\ & C8 & \langle 6,8\rangle \end{bmatrix};\ R_5 = \begin{bmatrix} P_5 & C1 & \langle 8,10\rangle \\ & C2 & \langle 8,10\rangle \\ & C3 & \langle 8,10\rangle \\ & C4 & \langle 8,10\rangle \\ & C5 & \langle 8,10\rangle \\ & C6 & \langle 8,10\rangle \\ & C7 & \langle 8,10\rangle \\ & C8 & \langle 8,10\rangle \end{bmatrix}$$

Then, the matter-element in controlled field R_p can be obtained as:

$$R_p = \begin{bmatrix} P & C1 & \langle 0,10\rangle \\ & C2 & \langle 0,10\rangle \\ & C3 & \langle 0,10\rangle \\ & C4 & \langle 0,10\rangle \\ & C5 & \langle 0,10\rangle \\ & C6 & \langle 0,10\rangle \\ & C7 & \langle 0,10\rangle \\ & C8 & \langle 0,10\rangle \end{bmatrix}$$

4.2. Set the Matter-Element to Be Evaluated

In this paper, the matter-element to be evaluated is the business risk of electricity retail company in China. To obtain the performance values of eight sub-criteria in the evaluation index system of business risk evaluation of electricity retail company, five experts including three university professors and two enterprise practitioners in the fields of enterprise risk management and electric power industry management are invited to value the performances of eight sub-criteria of electricity retail companies operating presently in China using a scoring system with a 10-point scale. The final performance values of eight sub-criteria are calculated by averaging the performance values of five experts for each sub-criteria, which are 3.6, 5.4, 6.1, 7.6, 8.4, 5.6, 4.9, and 2.3. Then, the matter-element to be evaluated R_0 can be obtained as:

$$R_0 = \begin{bmatrix} P_0 & C1 & 3.6 \\ & C2 & 5.4 \\ & C3 & 6.1 \\ & C4 & 7.6 \\ & C5 & 8.4 \\ & C6 & 5.6 \\ & C7 & 4.9 \\ & C8 & 2.3 \end{bmatrix}$$

It can be seen that the risk levels of different sub-criteria are different. The competition risk from other electricity retail company is very high. The potential cost increase risk and the uncertainties risk from electricity supply and demand are high. The electric bill recovery risk, business climate risk and policy uncertainty risk are medium. The electricity purchase and sale contracts signing risk and the policy implementation risk are low. On the whole, it is difficult to evaluate the comprehensive business risk level of electricity retail companies in China only considering these eight risk sub-criteria separately. Therefore, the MCDM technique needs to be employed to comprehensively evaluate the business risk level of electricity retail companies in China.

4.3. Determine the Weights of Risk Sub-Criteria

The BBWM is employed to determine the weights of eight risk sub-criteria in this paper. Those five experts including three university professors and two enterprise practitioners in the fields of enterprise risk management and electric power industry management are also invited for the weight determination of risk sub-criteria.

Firstly, the best risk sub-criterion and the worst risk sub-criterion were respectively determined by these five experts which are listed in Table 1.

Table 1. The best criterion and the worst criterion determined by five invited experts.

Expert Number	The Best Risk Sub-Criterion	The Worst Risk Sub-Criterion
1	C5	C8
2	C5	C1
3	C4	C7
4	C2	C6
5	C3	C8

Then, the pairwise comparisons between the best risk sub-criterion and all other seven risk sub-criteria were performed by these five invited experts, and the results are tabulated in Table 2. Meanwhile, the pairwise comparisons between the worst risk sub-criterion and all other seven risk sub-criteria were also performed by these five invited experts, and the results are listed in Table 3.

Table 2. Pairwise comparisons between the best risk sub-criterion and all other seven risk sub-criteria for five experts.

Expert Number	**1**	**2**	**3**	**4**	**5**
The Best Risk Sub-Criterion	**C5**	**C5**	**C4**	**C2**	**C3**
C1	6	7	5	3	3
C2	4	3	3	1	3
C3	4	4	4	2	1
C4	3	2	1	3	2
C5	1	1	2	2	2
C6	5	3	4	5	4
C7	7	5	6	4	5
C8	7	6	5	5	6

Table 3. Pairwise comparisons between the worst risk sub-criterion and all other seven risk sub-criteria for five experts.

Expert Number	**1**	**2**	**3**	**4**	**5**
The Worst Risk Sub-Criterion	**C8**	**C1**	**C7**	**C6**	**C8**
C1	2	1	3	3	2
C2	4	3	4	5	3
C3	4	3	3	3	6
C4	5	5	6	2	5
C5	7	6	4	3	4
C6	2	3	3	1	3
C7	2	3	1	2	2
C8	1	2	2	2	1

Therefore, the 'Best-to-Others' vector A_B can be obtained, namely

$$A_B = \begin{pmatrix} 6 & 4 & 4 & 3 & 1 & 5 & 7 & 7 \\ 7 & 3 & 4 & 2 & 1 & 3 & 5 & 6 \\ 5 & 3 & 4 & 1 & 2 & 4 & 6 & 5 \\ 3 & 1 & 2 & 3 & 2 & 5 & 4 & 5 \\ 3 & 3 & 1 & 2 & 2 & 4 & 5 & 6 \end{pmatrix}$$

Meanwhile, the 'Others-to-Worst' vector A_W can also be obtained, namely

$$A_W = \begin{pmatrix} 2 & 1 & 3 & 3 & 2 \\ 4 & 3 & 4 & 5 & 3 \\ 4 & 3 & 3 & 3 & 6 \\ 5 & 5 & 6 & 2 & 5 \\ 7 & 6 & 4 & 3 & 4 \\ 2 & 3 & 3 & 1 & 3 \\ 2 & 3 & 1 & 2 & 2 \\ 1 & 2 & 2 & 2 & 1 \end{pmatrix}$$

Then, the averages of Dirichlet distribution of w^{agg} can be calculated using MATLAB software, which are the optimal values of eight risk sub-criteria weights, namely 0.0867, 0.1477, 0.1417, 0.1790, 0.2013, 0.0961, 0.0777, and 0.0700. It can be seen that the competition risk from other electricity retail companies (C5) is the most important risk sub-criterion among eight sub-criteria, followed by uncertainties risk from electricity supply and demand (C4), electric bill recovery risk (C2), potential cost increase risk (C3), business climate risk (C6), electricity purchase and sale contracts signing risk (C1), policy uncertainty risk (C7), and policy implementation risk (C8).

Figure 3 shows the creedal ranking of eight sub-criteria for business risk evaluation of electricity retail company, which shows the degree of certainty about the relation of eight risk sub-criteria. For example, it can be learnt that the competition risk from other electricity retail companies (C5) is certainly more important than electricity purchase and sale contracts signing risk (C1) with the confidence of 1, and it is more desirable than uncertainties risk from electricity supply and demand (C4) with the confidence of 0.68; the uncertainties risk from electricity supply and demand (C4) is certainly more important than policy implementation risk (C8) with the confidence of 1, and it is more desirable than policy uncertainty risk (C7) with the confidence of 0.78.

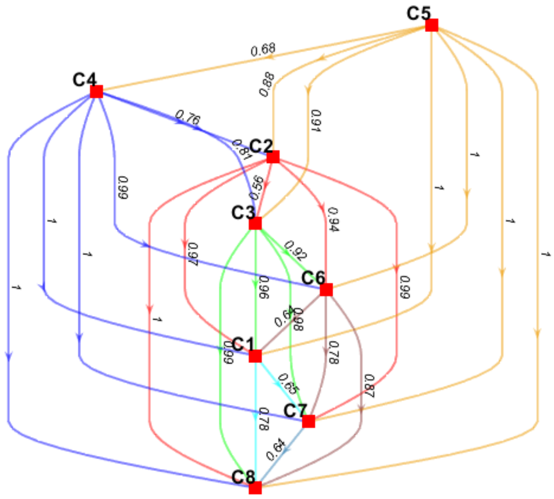

Figure 3. The credal ranking of eight risk sub-criteria for business risk evaluation of electricity retail company.

4.4. Calculate the Proximity Degrees of the Matter-Element to be Evaluated for Different Evaluation Grades

The proximity degrees of the matter-element to be evaluated (namely the business risk of electricity retail company in China) for different risk evaluation grades including VL, L, M, H, and VH can be calculated according to Equation (17), and the results are as follows:

$$N_1(p_0) = 1 - \frac{1}{8*(8+1)}\sum_{i=1}^{8} D_j(v_i)w_i = 0.9368,$$
$$N_2(p_0) = 1 - \frac{1}{8*(8+1)}\sum_{i=1}^{8} D_j(v_i)w_i = 0.9694,$$
$$N_3(p_0) = 1 - \frac{1}{8*(8+1)}\sum_{i=1}^{8} D_j(v_i)w_i = 0.9897,$$
$$N_4(p_0) = 1 - \frac{1}{8*(8+1)}\sum_{i=1}^{8} D_j(v_i)w_i = 0.9906,$$
$$N_5(p_0) = 1 - \frac{1}{8*(8+1)}\sum_{i=1}^{8} D_j(v_i)w_i = 0.9737.$$

where $N_1(p_0)$, $N_2(p_0)$, $N_3(p_0)$, $N_4(p_0)$, and $N_5(p_0)$ respectively represent the proximity degrees of business risk of electricity retail company in China for VL, L, M, H, VH grades.

4.5. Rank Business Risk Evaluation Grade of Electricity Retail Company

According to Equation (18), it can be obtained that $N_4(p_0) = \max\{N_j(p_0)\}(j = 1,2,3,4,5)$. Therefore, it can be concluded that the current business risk of electricity retail company in China is high.

According to Equation (19), it can be calculated that the variable eigenvalue $j^* = 3.5388$. The value j^* represents the attributive degree of business risk of electricity retail company tending to adjacent risk evaluation grade. In this paper, we use $j^* \in (0, 1), (1, 2), (2, 3), (3, 4)$, and $(4, 5)$ to respectively represent the business risk grades VL, L, M, H, VH of electricity retail company. For example, if $j^* = 2.3$, it shows that the business risk of electricity retail company belongs to 'Medium' grade but closer to the 'Low' grade more; if $j^* = 2.8$, it indicates that the business risk of electricity retail company belongs to 'Medium' grade but closer to the 'High' grade more. In this paper, $j^* = 3.5388 \in (3, 4)$, so the current business risk of electricity retail company in China belongs to 'High' grade and closer to the 'Very High' grade more.

5. Discussion

In this section, the result obtained by the proposed method will be analyzed. Meanwhile, another MCDM method will be selected to evaluate the business risk of electricity retail company, and its result will be compared with that of the proposed method in this paper.

5.1. Result Analysis

In this paper, the business risk of electricity retail company in China is evaluated by the proposed MCDM method which combines the BBWM and improved matter-element extension model, and the result indicates that the comprehensive business risk of electricity retail company in China is high. In order to obtain better insight from the proposed MCDM method application on business risk of electricity retail company, it will probe into the weights and performances of risk sub-criteria.

Figure 4 displays the weights of eight risk sub-criteria, and the performances of these eight risk sub-criteria are shown in Figure 5. In Figure 4, it can be seen that the weights of competition risk from other electricity retail companies (C5), uncertainties risk from electricity supply and demand (C4), electric bill recovery risk (C2), and potential cost increase risk (C3) (in descending order) are more than 0.1, which indicate that these four risk sub-criteria are more important for business risk evaluation of electricity retail company compared with other risk sub-criteria. According to Figure 5, the competition risk from other electricity retail companies is very high; the uncertainties risk from electricity supply and demand and the potential cost increase risk are high; the business climate risk, electric bill recovery risk, and policy uncertainty risk are medium; the electricity purchase and sale contracts signing risk and policy implementation risk are low. Therefore, it can be seen that the competition risk from other electricity retail companies, the uncertainties risk from electricity supply and demand and the potential cost increase risk are quite high, and meanwhile their weights values are much larger than other risk sub-criteria. Therefore, considering the above-mentioned points, the current business risk level of electricity retail companies in China is 'High' grade. The electricity retail company manager should pay more attention to the competition risk from other electricity retail companies, uncertainties risk from electricity supply and demand, and potential cost increase risk.

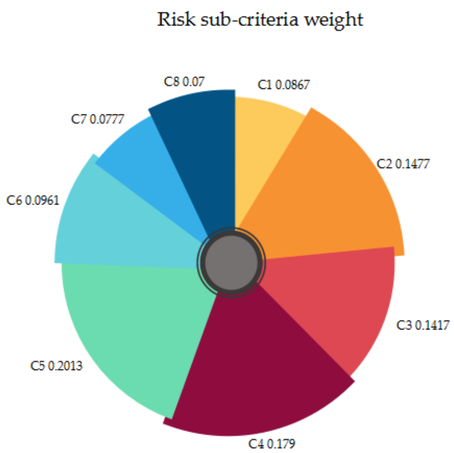

Figure 4. The weights of business risk sub-criteria of electricity retail company.

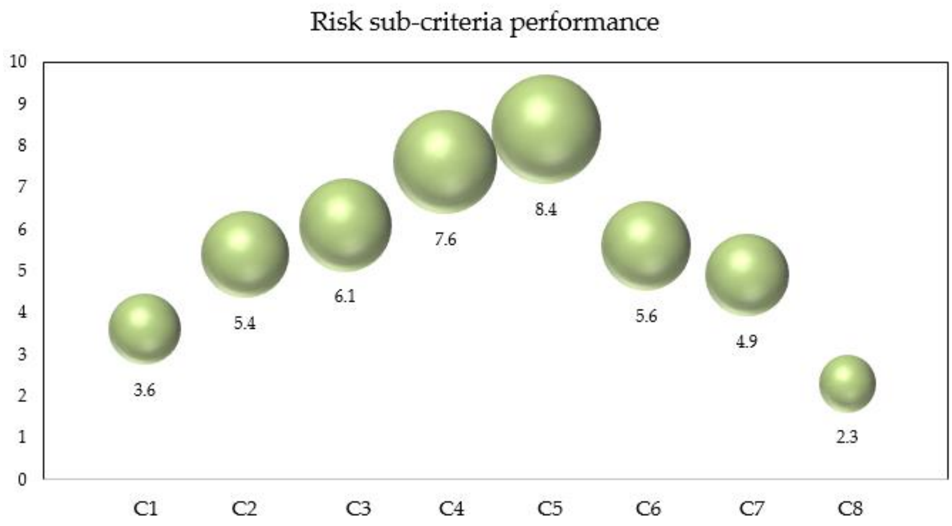

Figure 5. The business risk sub-criteria performances of electricity retail company.

5.2. Comparative Analysis

The fuzzy comprehensive evaluation method has been employed for risk evaluation in many fields, such as large-scale seawater desalination projects [54], flood risk assessment [55], virtual reality mine safety training system [56], and a UHV power transmission construction project [57]. Therefore, the fuzzy comprehensive evaluation method is selected as the comparative method with the proposed method in this paper, and the results of these two methods will be comparatively analyzed.

For the business risk evaluation of electricity retail companies in China using the fuzzy comprehensive evaluation, the risk level of electricity retail company is also set as five grades, namely very low (VL), low (L), medium (M), high (H), and very high (VH). Meanwhile, just as the same of the setting of the matter-elements in classical field in Section 4.1, the values of risk sub-criteria in the range of 0–2, 2–4, 4–6, 6–8 and 8–10 represent very low business risk, low business risk, medium business risk, high business risk and very high business risk, respectively. Therefore, according to the judgements and feedbacks of five experts on eight risk sub-criteria performances, the fuzzy relation matrix F can be obtained as follows:

$$F = \begin{bmatrix} 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0 & 0.6 & 0.4 \\ 0 & 0 & 0 & 0.2 & 0.8 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0.8 & 0.2 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \end{bmatrix}$$

Then, according to the weights of eight risk sub-criteria obtained using the BBWM, the fuzzy comprehensive evaluation matrix B can be calculated as:

$$B = (b_1, b_2, b_3, b_4, b_5) = w^T \circ F = \begin{pmatrix} 0.0867 \\ 0.1477 \\ 0.1417 \\ 0.1790 \\ 0.2013 \\ 0.0961 \\ 0.0777 \\ 0.0700 \end{pmatrix}^T \circ \begin{bmatrix} 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0 & 0.6 & 0.4 \\ 0 & 0 & 0 & 0.2 & 0.8 \\ 0 & 0 & 0.4 & 0.6 & 0 \\ 0 & 0 & 0.8 & 0.2 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \end{bmatrix}$$
$$= \begin{pmatrix} 0.0280 & 0.0627 & 0.2824 & 0.3945 & 0.2326 \end{pmatrix}$$

According to the maximum membership degree principle of fuzzy comprehensive evaluation method, it can be deduced that $b_4 = \max b_i (1 \le i \le 5)$. Therefore, it can be judged that the business risk level of electricity retail companies in China belong to 'High' grade. The business risk level of electricity retail companies in China was evaluated by using the proposed MCDM method in this paper and the fuzzy comprehensive evaluation method is consistent. Further, it can be seen that the proposed MCDM method for business risk evaluation of electricity retail companies in this paper is effective and practical.

6. Conclusions

A new-round marketization reform of electricity industry is ongoing in China, and the degradation of the electricity retail market is a principal focus. With the introduction of competition into the electricity retail market, increasingly more electricity retail companies have been founded, which will spur competition in the electricity retail market. Meanwhile, electricity retail companies today face more kinds of risk, not only economic operation risk, but also marketable risk and political risk. So, it is very important to evaluate the business risk of electricity retail company, which can aid the electricity retail company to identify the risk, reduce risk loss and promote sustainable development. In this paper, a new hybrid MCDM framework for business risk of electricity retail companies is proposed, which combines the BBWM for determining the weights of business risk criteria and the improved matter-element extension model for ranking the comprehensive business risk level of electricity retail company. The empirical analysis shows that the current comprehensive business risk level of electricity retail company in China belongs to 'High' grade. Meanwhile, the variable eigenvalue j^* indicates that the current comprehensive business risk level of electricity retail companies in China is closer to the 'Very High' grade. Thus implies the business risk of electricity retail companies in China will increase in the future, especially under the situation that more and more electricity retail companies will be founded.

According to the evaluation result, it can be concluded that electricity retail company managers should pay more attention to the competition risk from other electricity retail companies, uncertainties risk from electricity supply and demand, and potential cost increase risk. Therefore, several recommendations for the risk management of electricity retail companies are proposed. Firstly, electricity retail companies should enhance competitiveness, improve service quality, meet the diversified demand of key consumers, guarantee the safe and stable electricity supply for electricity consumers, and allocate more resources to high quality customers to earn more profit. Meanwhile, companies should analyze competitor behavior and try to cooperate with strong competitors to draw on each other's strengths. Secondly, electricity retail companies should enhance the capacity of electricity forecasting. It should improve the forecasting accuracy related to electricity demand of consumers and electricity supply of electricity generators, and try to use the latest techniques such as big data and deep learning for electricity forecasting and then develop electricity forecasting system for practical convenient application in routine work. Meanwhile, the fluctuant policy and social economic environment should be addressed for electricity forecasting modelling. Thirdly, electricity retail companies should lower the cost, employ advanced cost management methods, such as the incremental scheduling method, to reduce electricity cost, give preference to the generators with a low price in different regions for electricity purchase, and timely monitor the implementation effect of an electricity purchasing and selling plan.

Although it is verified that the proposed new hybrid MCDM model is feasible and applicable for the business risk evaluation of electricity retail companies, considering the complexity and uncertainty of electricity marketization reform, with the further development of the electricity retail market, the business risk evaluation index system can be improved in the future. Meanwhile, the new hybrid MCDM method proposed in this paper can also be used for other issues, such as business risk evaluation for electricity generation companies and power grid enterprises.

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