A Hybrid MCDM Model for Evaluating the Market-Oriented Business Regulatory Risk of Power Grid Enterprises Based on the Bayesian Best-Worst Method and MARCOS Approach

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Abstract: As a result of the deepening of China’s power system reform, the market-oriented business development of power grid enterprises is in full swing. However, most of the existing research has focused on the regulatory risks of the regulatory business for power grid enterprises, while ignoring the regulatory risks faced by market-oriented businesses. In order to promote the sustainable development of market-oriented business, a comprehensive regulatory risk assessment framework was constructed for the market business of power grid enterprises. First, the risk assessment index system was constructed from the perspectives of policy risk, business isolation risk, market risk, and safety risk. Then, a novel hybrid multi-criteria decision-making (MCDM) model based on the Bayesian best-worst method and the measurement alternatives and ranking according to the compromise solution approach, was adopted. Finally, eight market-oriented businesses were selected as case studies. The result indicates that organizational isolation risk and operational security risk are the key regulatory risks of the market-oriented business for power grid enterprises. Compared with two other MCDM models, the proposed hybrid MCDM model has good applicability and effectiveness for risk evaluation of the regulatory business. The results of this research can provide support for power enterprises to deal with market-oriented business supervision, and can also provide a reference for power industry regulators.

Keywords: market-oriented business; regulatory risk; Bayesian best-worst method; MARCOS approach

1. Introduction

1.1. Background and Motivation

Under the reform of China’s power system in 2015, the power generation side and the power sales side of the market gradually opened up, allowing multiple subjects to participate in the power market [1]. In this context, power grid enterprises have carried out more market-oriented businesses, such as electric vehicle services, e-commerce, and integrated energy, and formulated a series of market-oriented business development strategies and action plans.

However, as a result of the deepening of electricity marketization reform, the regulatory and regulated relationship between the government and power grid enterprises has undergone profound changes. Under the new regulatory relationship, the regulatory boundary has been gradually clarified and the regulatory caliber has been gradually tightened, leading to a significant increase in the regulatory risks faced by power grid enterprises in their market-oriented business. Hence, it is necessary to identify the regulatory risks of the market-oriented business for power grid enterprises, which can help the company to improve their ability of preventing regulatory risks. Furthermore, the assessment of the
market-oriented business regulatory risks of power grid enterprises can lay a solid foundation for the company to maintain a strategic concentration and competitive advantages in the continuous deepening of reforms, which can also ensure the healthy and sustainable development of the company.

1.2. Literature Review

Risk assessment is an enduring problem, and any type of enterprise will inevitably encounter various risks in the course of operation. Some scholars are concerned about individual risks, such as security [2], supply chain [3], and credit [4], whereas others focus more on building a comprehensive and systematic risk assessment framework [5–7].

As an important part of the energy sector, the electric power industry plays an important role in the development of the national economy [8,9]. In recent years, the research on the risk of power enterprises has attracted more and more attention. Some scholars concentrate on the risks faced by the enterprise itself. Liu [10] constructed a comprehensive financial risk control system for power companies, which can help improve the financial risk control ability of power companies. The result indicates that solvency is the key factors leading to the financial risk of power grid enterprises. To strengthen risk management in power grid enterprises, Liu et al. [11] constructed a management and control system for electricity bill risks. Jin and Zhou [12] evaluated the risks of some thermal power enterprises in East China based on AHP. The result shows that accidents are a key risk factor for thermal power plant operations. Zhe et al. [13] evaluated the financial risk of Linfen Power Supply Company, and the result shows that a high debt rate may result in difficulties in paying off debts and refinancing.

Some scholars focus more on the risks faced by power engineering or power projects. Ma et al. [14] evaluated the comprehensive risk of a power engineering project based on grey relational analysis (GRA) and AHP. The proposed model integrates subjective and objective weighting methods, and is suitable for power engineering project risk assessment. Zhang et al. [15] established a risk evaluation index system from the perspective of environmental risk, economic risk, technical risk, management risk, and market risk. The results indicate that economic risk and technical risk are the most important risk factors. Wang [16] applied the work breakdown structure and risk breakdown structure (WBS-RBS) method to identify the risk factors of the cost of power grid engineering during five major engineering cost formation stages, which enables the power grid construction company to prevent risks in the construction process. Li et al. [17] constructed a process which initially simulated the NPV with the Monte Carlo method, which can help assess the investment risk of a wind power project. The result shows that the wind power electricity connected to the grid exerts a dramatic influence on investment risk, so it should be increased to reduce the risk.

In addition, some scholars also studied the regulatory risks faced by power grid enterprises. Arango et al. [18] studied the company’s electricity price pricing method under the condition of risk, thus helping ANEEL to regulate the electric power enterprises. As climate risks have a large impact on energy costs, regulators need to strengthen their oversight of these areas. Fang et al. [19] established a systematic transaction supervision risk index for quantifying and unifying the risk level of the interconnected power market. This research shows that there is a need to strengthen the supervision of electricity market trading links. Sasaki and Nakayama [20] reveal the potential risks of a project of Eskom, and suggest concentrating on the most important risks: regulatory risk, political risk, and financial risk. Li et al. [21] estimated the electricity transmission and distribution tariff regulation risk based on the fuzzy best-worst method (FBWM) and the improved fuzzy comprehensive evaluation method. The result shows that the electricity transmission and distribution tariff compliance risk is the main regulatory risk factor faced by power grid companies. Although there have been some studies on the risks of the power industry, there are still some deficiencies:
(1) There are few studies on the regulatory risk of power grid enterprises. Most of the studies only analyze regulatory risk as a part of grid risk, and do not specifically study the multi-dimensional regulatory risk of grid companies. The evaluation results are not comprehensive or complete.

(2) There is a lack of research on the market-oriented business regulatory risk assessment for power grid enterprises. Existing studies mainly focus on regulatory business, or do not distinguish between market-oriented business and regulatory business. However, with the operation of the electricity market, the government has continuously emphasized the need to clarify the boundaries between the regulatory business and market-oriented business. The research on the regulatory risk of the market-oriented business for power grid enterprises is conducive to comprehensively grasping the regulatory risks faced by power grid enterprises.

1.3. Contributions and Article Organization

In this study, we drew on market supervision research in the fields of energy [22] and finance [23], and assessed the market-oriented business regulatory risk of power grid enterprises. First, the regulatory risk assessment index system of market-oriented business for power grid enterprises was constructed from four dimensions: policy risk, business isolation risk, market risk, and safety risk. Second, the regulatory risk indicators were weighted and evaluated based on the Bayesian best-worst method (BBWM) and the measurement alternatives and ranking according to compromise solution (MARCOS) approach. Then, eight market-oriented business were selected as case studies. Finally, the evaluation results were compared with the results of the BWM-MARCOS model and the BBWM-TOPSIS model, which verified the effectiveness and superiority of the proposed model.

The risks faced by the market-oriented business of power grid enterprises can be clarified through the research conducted in this study. The evaluation results can help power grid enterprises to improve risk prevention and control, which can also improve the market-oriented operation ability of power grid enterprises. In addition, this paper further proposes a novel hybrid MCDM method to solve decision-making problems such as risk assessment. The main contributions of this paper are listed as follows:

(1) In view of the new regulatory relationship faced by power grid enterprises, this paper proposes a set of indicators that comprehensively reflect the market-oriented business regulatory risks of power grid enterprises, covering policy risk, business isolation risk, market risk, and safety risk. The comprehensive evaluation index system can fill the gap in the existing research and is of great significance for power grid enterprises to actively adapt to supervision and prevent supervision risks.

(2) A market-oriented business regulatory risk assessment model of power grid enterprises based on BBWM-MARCOS is proposed in this paper. In the BBWM approach, Bayesian theory is introduced into the traditional BWM to form a certain decision-making environment, which can reduce the heterogeneity between indicators. Compared with the traditional TOPSIS method, MARCOS considers both the ideal solution and the anti-ideal solution, indicating that MARCOS has more significant stability and reliability, and better sample resolution.

The structure of this paper is as follows. After the introduction, the second section presents the construction of the market-oriented business regulatory risk index system, and expounds the connotation of indicators. Section 3 mainly illustrates the basic theories of the Bayesian best-worst method and the MARCOS approach. Section 4 evaluates the comprehensive regulatory risk of eight market-oriented businesses. Section 5 compares the evaluation results with other models, and the conclusions are given in Section 6.

2. Evaluation Index System of Market-Oriented Business Regulatory Risk for Power Grid Enterprises

Designing a scientific and reasonable evaluation index system is the basis and key to market-oriented business regulatory risk evaluation. The index system must include
open, wide, and specific indicators that can show the basic features and meaning of the market-oriented business regulatory risk [24–26]. This paper comprehensively considers the risks of four dimensions: policy, business isolation, market, and security. The regulatory risk evaluation index system of market-oriented business for power grid enterprises is shown in Figure 1.

![Regulatory risk evaluation index system of market-oriented business for power grid enterprises](image)

**Figure 1.** Regulatory risk evaluation index system of market-oriented business for power grid enterprises.

1. **Policy risk.**

   Affected by the external environment, the government may issue some important regulations or revise existing policies, while the strategic direction of power grid enterprises may deviate from or be inconsistent with the policy orientation. Therefore, this paper believes that policy risk mainly includes reverse policy risk and abrupt policy risk [27].

2. **Business isolation risk.**

   As the key to the reform of the power system, it is necessary to realize the separation between the regulated business and the market-oriented business. However, due to the incomplete separation or insufficient separation between the market-oriented business and the main business of power grid companies, some market entities abuse their power positions and affect the fair competition in the power market [28]. Therefore, the degree of business separation is regarded as the main manifestation of the marketization process, and the risk of business separation is also one of the key regulatory risks for power grid enterprises. Organizational isolation risk, financial isolation risk [29], and legal isolation risk are selected in this paper.

3. **Market risk.**

   Although the government believes that the electricity market should expand competition, it still needs to carry out certain supervision of the access and trading behavior of market participants. Grid companies that do not have the qualifications or have illegal
and dishonest records are not allowed to participate in the market; in addition, power grid companies must not interfere with the normal market order in market transactions. Hence, market access risk and market transaction risk are selected in this paper.

(4) Safety risk.

During the construction and operation period of the grid project, it is inevitable that certain security risks will exist. Therefore, it is necessary to supervise the construction safety risks [30] and operational safety risks [31] of the market-oriented business of power grid enterprises. Meanwhile, the confidentiality of information and the improvement in software facilities are becoming much more important. Therefore, information security risk [32] is also selected as one of the safety risks that needs to be supervised.


3.1. Bayesian Best-Worst Method for Weight Determination of Evaluation Indicators

In general, weighting methods mainly include objective weighting methods and subjective weighting methods. The former mainly includes the entropy weight method [33] and principal component analysis [34], and the principle is based on the data characteristics of each evaluation object. The objective weighting method can realize the weighting of indicators through a data-driven approach, which can reduce the factors of human interference. Among the subjective weighting methods, methods such as analytic hierarchy process [35] and analytical network process [36] are widely used. These methods mainly rely on the experience of experts and related scholars, and artificially empower some indicators that cannot be measured quantitatively. Since most of the regulatory risks faced by market-oriented businesses are qualitative indicators and cannot be quantified, the objective weighting method that relies too much on sample size and sample richness is obviously unable to be applied to the assessment of regulatory risks of market-oriented businesses.

In 2015, the best-worst method (BWM) was first applied by Rezaei, and can effectively reduce the number of comparisons between indicators [37]. The steps are shown as follows:

Step 1: For the evaluation index of the supervision risk of the market-oriented business of power grid enterprises \( \{c_1, c_2, \cdots, c_n\} \), determine the best indicator \( c_B \) and the worst indicator \( c_W \).

Step 2: Compare \( c_B \) with other indicators \( c_j \), and use the numbers 1–9 to represent the importance between \( c_B \) and other indicators \( c_j \); 1 means that the importance of \( c_B \) is equal to \( c_j \), and 9 means that \( c_B \) is much more important than \( c_j \). The “Best-to-Others” vector \( A_B \) can be expressed as follows:

\[
A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})
\]  

Step 3: Compare \( c_W \) with other indicators \( c_j \), and use the numbers 1–9 to represent the importance between \( c_W \) and other indicators \( c_j \); 1 means that the importance of \( c_j \) is equal to \( c_W \), 9 means that \( c_j \) is much more important than \( c_W \), and the “Others-to-Worst” vector \( A_W \) can be expressed as follows:

\[
A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})
\]  

Step 4: Determine the optimal weights of indicators \( (\omega_1^*, \omega_2^*, \omega_3^* \cdots \omega_n^*) \). The maximum absolute differences \( |\frac{w_B}{w_j} - a_{Bj}| \) and \( |\frac{w_j}{w_W} - a_{jW}| \) should be minimized.

\[
\min_{\omega_i^*} \left\{ \begin{array}{l}
|\frac{w_B}{w_j} - a_{Bj}|, \quad |\frac{w_j}{w_W} - a_{jW}|
\end{array} \right. 
\]  

\[
\sum_j w_j = 1 \\
w_j \geq 0, j = 1, 2 \cdots n
\]
The optimal weights can be calculated by Equation (5).

\[
\begin{align*}
\text{s.t.} & \quad \begin{cases} 
\min \xi \\
\frac{|w_j - a_{Bj}|}{|w_j - a_{Wj}|} \leq \xi \\
\sum w_j = 1 \\
w_j \geq 0, j = 1, 2 \ldots n
\end{cases}
\end{align*}
\] (5)

Step 5: Calculate the consistency ratio (CR). The closer CR is to 0, the more reasonable the results [38]. When the consistency ratio is 0, the opinions of each expert are completely consistent.

\[
\lambda_{CR} = \frac{\xi}{\lambda_{CI}}
\] (6)

where \(\lambda_{CR}\) represents the consistency ratio; \(\lambda_{CI}\) refers to the consistency index, which is the fixed value.

However, BWM can only calculate the weighting results of one expert at one time. When multiple experts need to determine the weight together, the weighting results of experts are often averaged to obtain the final weighting results. The process of averaging the weights will lead to outlier sensitivity and restricted information provision problems [24]. Only when extended to the group decision-making environment can we obtain more reliable weights.

In 2019, Mohammadi and Rezaei proposed the BBWM method, which introduced Bayesian theory into the traditional BWM method [39]. The main improvement of BBWM is to consider the probabilistic interpretations of the inputs and outputs, which means that each index is regarded as a random event, and the weight is regarded as the possibility of each event. Taking the worst index \(c_W\) as an example, its polynomial probability distribution function can be expressed as:

\[
P(A_W|w) = \left( \frac{\sum_{j=1}^{n} a_{jW}}{\prod_{j=1}^{n} a_{jW}^j} \right)^{n} \prod_{j=1}^{n} \frac{w^{a_{jW}^j}}{w}
\] (7)

where \(w\) represents the probability distribution.

The probability of event \(j\) is proportionate to the number of occurrences for the event:

\[
w_j \propto \frac{a_{jW}}{\sum_{j=1}^{n} a_{jW}^j}
\] (8)

Suppose there are \(K\) decision makers, so the \(k^{th}\) \((k = 1, 2 \ldots K)\) pairwise comparison vector can be represented as \(A^k_B\) and \(A^k_W\), and the \(k^{th}\) weight can be expressed as \(w^k\). The overall optimal weight \(\overline{w}^{agg}\) can be calculated by \(w^k\). Then, the joint probability distribution can be expressed as Equation (9):

\[
P(\overline{w}^{agg}, w^1:K | A^1_B, A^1_W) = \prod_{k=1}^{K} P(w^k | A^k_B, A^k_W)
\] (9)

The probability of each individual variable can be obtained by Equation (10):

\[
P(x) = \sum_{y} P(x, y)
\] (10)

where \(x\) and \(y\) represent the arbitrary random variables.

After calculating the weighting results of each index, it is necessary to further judge whether the opinions among experts are consistent. Ref. [39] proposed a consistency test
The principle is to calculate the importance comparison probability between indexes $C_i$ and $C_j$ by introducing Bayesian theory. 

$$P(C_i > C_j) = \int I_{w_{agg}^i > w_{agg}^j} P(w_{agg})$$  \hspace{1cm} (11)$$

where $P(w_{agg})$ represents the posterior distribution of $w_{agg}$. When the subscript condition of $I$ is satisfied, the value is 1, otherwise it is 0. The value range of credal ranking among indicators is $[0, 1]$. When the value is closer to 1, it indicates that the consistency of weight setting of experts is higher. In the BBWM method, the threshold value of credal ranking value is set as 0.5, indicating that if the credal ranking value does not reach 0.5, there are large differences in opinions among experts. Then, experts need to renegotiate the indicator weights.

### 3.2. MARCOS for Evaluation of Market-Oriented Business Regulatory Risk

In the evaluation of market-oriented business regulatory risks for power grid enterprises, the effective ranking of various alternatives is essential to the final evaluation results. For this purpose, the matter-element extension model [40] and TOPSIS [41] are commonly used methods. However, the former mainly evaluates a single item, and the result is also used to analyze the membership degree of the evaluation object to each level. When it is necessary to compare the advantages and disadvantages of multiple alternatives, the matter-element extension method is obviously not applicable. Although TOPSIS is simple to operate and can also realize the ranking for each object, it focuses on analyzing the distance between each alternative and the anti-ideal solution, which ignores the ideal solution. The measurement of alternatives and ranking order to compare solution (MARCOS) approach is applied in this paper, which calculates the comprehensive utility function of the alternatives on the basis of calculating the distance (utility) of the alternatives relative to the positive and anti-ideal solutions [42–44]. Then, the options are sorted according to the utility function, which resolves the shortcomings of the TOPSIS method. The procedures of MARCOS are elaborated as below:

**Step 1:** Formation of an initial decision-making matrix. Assuming that there are $m$ alternatives, $n$ indicators, and the indicator value is $x_{ij}$, then, the original decision matrix $X$ can be expressed as $[x_{ij}]_{m \times n}$.

**Step 2:** Normalize the initial matrix. The standardized value of cost indicators can be obtained by Equation (12). The standardized value of performance indicators can be obtained by Equation (13).

$$n_{ij} = \frac{1}{x_{ij}} \hspace{1cm} (12)$$

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \hspace{1cm} (13)$$

**Step 3:** Determine the weighting matrix $R = [r_{ij}]_{m \times n}$. The normalization matrix is multiplied by the weight of the criterion $w_j$ to obtain the weighting matrix $R$.

$$r_{ij} = n_{ij} \times w_j \hspace{1cm} (14)$$

**Step 4:** Determine the positive and anti-ideal solutions. The expansion of the original decision matrix is realized by determining the ideal solution $S^+$ and the anti-ideal solution $S^-$, which can be obtained by Equations (15) and (16):

$$S^+ = \{s_1^+, s_2^+, \ldots, s_i^+, \ldots, s_n^+ \} \hspace{1cm} s_i^+ = \max_j r_{ij} \hspace{1cm} (15)$$

$$S^- = \{s_1^-, s_2^-, \ldots, s_i^-, \ldots, s_n^- \} \hspace{1cm} s_i^- = \min_j r_{ij} \hspace{1cm} (16)$$
Step 5: Calculate the utility of each alternative. Using Equations (17) and (18), calculate the utility degree of the alternative schemes relative to the ideal solution and the anti-ideal solution.

\[ K(j)^- = \sum_{i=1}^{n} s_i / S^- \]  
\[ K(j)^+ = \sum_{i=1}^{n} s_i / S^+ \]  

Step 6: Calculate the utility function. The utility function \( f(K_j) \) is obtained by compromising the distance between the alternative solution and the positive and anti-ideal solution. Equation (19) can be used to calculate the utility function.

\[ f(K_j) = \frac{K(j)^+ + K(j)^-}{1 + \frac{1-f(K_j^-)}{f(K_j^-)} + \frac{1-f(K_j^+)}{f(K_j^+)} + 1} \]  

where the meaning of \( f(K_j^-) \) is the utility function relative to the anti-ideal solution and the meaning of \( f(K_j^+) \) is the utility function relative to the ideal solution. Equations (20) and (21) are used to calculate the utility functions relative to the positive and anti-ideal solution.

\[ f(K_j^+) = \frac{K(j)^+}{K(j)^+ + K(j)^-} \]  
\[ f(K_j^-) = \frac{K(j)^-}{K(j)^+ + K(j)^-} \]  

Step 7: Rank the alternatives.

3.3. The Framework of the Proposed Model

Figure 2 shows the framework of the proposed model:

![Figure 2. The framework of the proposed model.](image-url)
4. Case Study

4.1. Basic Information

For this section, we selected eight market-oriented businesses of a power grid company for empirical analysis, and invited five experts to score each risk index. Of these, two experts are from the market-oriented business department of a power grid enterprise, one expert is from the scientific research institution under a power grid enterprise, one expert is from a government regulatory agency, and the fifth expert is from a university that studies the power market. The range of scores is 0–10; the higher the score, the higher the risk level of the item.

4.2. Determine the Weights of Risk Evaluation Indicators

According to the steps of BBWM, experts first need to determine the best and worst indicators of the market-oriented business regulatory risk evaluation index system, as shown in Table 1.

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

<table>
<thead>
<tr>
<th>Expert Number</th>
<th>The Best Indicator</th>
<th>The Worst Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C3</td>
<td>C6</td>
</tr>
<tr>
<td>2</td>
<td>C3</td>
<td>C6</td>
</tr>
<tr>
<td>3</td>
<td>C7</td>
<td>C6</td>
</tr>
<tr>
<td>4</td>
<td>C9</td>
<td>C1</td>
</tr>
<tr>
<td>5</td>
<td>C3</td>
<td>C1</td>
</tr>
</tbody>
</table>

On the basis of selecting the best and worst indicators, each expert gives the paired comparisons between the best indicators and other indicators, and the paired comparisons between the worst indicators and other indicators. Then, the optimal comparison vector $A^1_B$ and the worst comparison vector $A^1_W$ can be obtained as follows:

$A^1_B = \begin{pmatrix} 7 & 4 & 1 & 5 & 6 & 8 & 2 & 4 & 3 & 5 \\ 7 & 3 & 1 & 5 & 6 & 7 & 3 & 4 & 2 & 5 \\ 8 & 4 & 3 & 5 & 5 & 7 & 5 & 3 & 4 & 3 & 5 \end{pmatrix}$

$A^1_W = \begin{pmatrix} 2 & 5 & 8 & 4 & 3 & 1 & 8 & 5 & 6 & 4 \\ 1 & 5 & 7 & 3 & 2 & 1 & 5 & 4 & 6 & 3 \\ 2 & 7 & 7 & 4 & 3 & 1 & 8 & 5 & 6 & 3 \end{pmatrix}$

$K = 5$ means that five experts were invited to participate in the decision process. The values of the weights for ten indicators are listed in Table 2.

Table 2. Weights of ten criteria.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value of Weights</th>
<th>Indicator</th>
<th>Value of Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.0480</td>
<td>C6</td>
<td>0.0481</td>
</tr>
<tr>
<td>C2</td>
<td>0.1157</td>
<td>C7</td>
<td>0.1296</td>
</tr>
<tr>
<td>C3</td>
<td>0.1735</td>
<td>C8</td>
<td>0.1097</td>
</tr>
<tr>
<td>C4</td>
<td>0.0908</td>
<td>C9</td>
<td>0.1452</td>
</tr>
<tr>
<td>C5</td>
<td>0.0680</td>
<td>C10</td>
<td>0.0715</td>
</tr>
</tbody>
</table>

It is not difficult to see that the weight of organizational isolation risk (C3) index is relatively the highest, followed by operational security risk (C9) and market transaction risk (C7). In contrast, the weight of reverse policy risk (C1) index is the lowest. In recent years,
government regulators have strictly controlled power grid companies and accelerated the separation between the market-oriented business and the regulated business. The weighting result also indicates the importance of organizational isolation, which is the same as the requirements mentioned in “Anti-Monopoly Law” [45] and the “Regulations on Optimizing the Business Environment” [46]. In addition, as the leaders of the power industry, power grid enterprises are not prone to policy deviations or violations, so the weight of reverse policy risk is relatively low.

In order to ensure the consistency of the opinions for experts, the credal ranking value of each index was further measured, as shown in Figure 3.

![Figure 3. The credal ranking of indicators for the performance evaluation of market-oriented business.](image)

According to Figure 3, the consistency ratio between indicators can be clearly obtained. Taking organizational isolation risk (C3) as an example, the credal ranking values from C3 to C1, C4, C5, C6 and C10 are 1, which means that all the experts agree that this index is more important than the five other indexes. When comparing with C2, C7, and C8, the credal ranking values are 0.96, 0.9, and 0.97 respectively. In particular, when determining the importance of the C1 index and C9 index, there are relative differences among the experts, and the credal ranking value is 0.79. On the whole, however, the credal ranking value of each index exceeds 0.5, which proves that the opinions of experts are relatively consistent.

4.3. Determine the Ranking of Alternatives

(1) Determine the initial matrix. Gather the evaluation information of experts on the market-oriented business regulatory risk assessment indicators to generate the initial decision matrix, as shown in Table 3.
Table 3. Initial decision matrix for market-oriented business regulatory risk assessment.

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>A2</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>A4</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>A5</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>A6</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>A7</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>A8</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

(2) Determine the weighted normalization matrix. In the evaluation system, the smaller the index value, the smaller the regulatory risk faced by market-oriented business. Therefore, all of the indicators are cost-type indicators. On this basis, the normalization matrix is obtained by normalization according to Equations (12) and (13). Then, according to the weights determined by BBWM, the weighted normalization matrix is generated, as shown in Table 4.

Table 4. Weighted normalization matrix for regulatory risk assessment of market-oriented business.

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.0288</td>
<td>0.0868</td>
<td>0.0605</td>
<td>0.0136</td>
<td>0.0160</td>
<td>0.0741</td>
<td>0.0274</td>
<td>0.0484</td>
<td>0.0143</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>0.0360</td>
<td>0.1157</td>
<td>0.0454</td>
<td>0.0170</td>
<td>0.0120</td>
<td>0.0864</td>
<td>0.0183</td>
<td>0.0726</td>
<td>0.0358</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>0.0480</td>
<td>0.0694</td>
<td>0.1388</td>
<td>0.0908</td>
<td>0.0680</td>
<td>0.0481</td>
<td>0.1296</td>
<td>0.0366</td>
<td>0.0415</td>
<td>0.0179</td>
</tr>
<tr>
<td>A4</td>
<td>0.0480</td>
<td>0.0868</td>
<td>0.1157</td>
<td>0.0363</td>
<td>0.0340</td>
<td>0.0241</td>
<td>0.1296</td>
<td>0.1097</td>
<td>0.1452</td>
<td>0.0358</td>
</tr>
<tr>
<td>A5</td>
<td>0.0360</td>
<td>0.1157</td>
<td>0.1735</td>
<td>0.0605</td>
<td>0.0170</td>
<td>0.0241</td>
<td>0.0864</td>
<td>0.0219</td>
<td>0.0581</td>
<td>0.0715</td>
</tr>
<tr>
<td>A6</td>
<td>0.0240</td>
<td>0.0579</td>
<td>0.0991</td>
<td>0.0303</td>
<td>0.0136</td>
<td>0.0120</td>
<td>0.0864</td>
<td>0.0366</td>
<td>0.0726</td>
<td>0.0179</td>
</tr>
<tr>
<td>A7</td>
<td>0.0288</td>
<td>0.1157</td>
<td>0.0991</td>
<td>0.0908</td>
<td>0.0170</td>
<td>0.0241</td>
<td>0.0741</td>
<td>0.0219</td>
<td>0.0726</td>
<td>0.0238</td>
</tr>
<tr>
<td>A8</td>
<td>0.0360</td>
<td>0.0868</td>
<td>0.1388</td>
<td>0.0454</td>
<td>0.0170</td>
<td>0.0160</td>
<td>0.1037</td>
<td>0.0274</td>
<td>0.0484</td>
<td>0.0238</td>
</tr>
</tbody>
</table>

(3) Determine the ideal and anti-ideal solution. According to Table 4, the expansion matrix is generated by Equations (15) and (16). The ideal solution $S^+$ and the anti-ideal solution $S^-$ are shown in Table 5.

Table 5. The ideal solution and anti-ideal solution of each index.

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S^+$</td>
<td>0.0480</td>
<td>0.1157</td>
<td>0.1735</td>
<td>0.0908</td>
<td>0.0680</td>
<td>0.0481</td>
<td>0.1296</td>
<td>0.1097</td>
<td>0.1452</td>
<td>0.0715</td>
</tr>
<tr>
<td>$S^-$</td>
<td>0.0240</td>
<td>0.0579</td>
<td>0.0868</td>
<td>0.0303</td>
<td>0.0136</td>
<td>0.0120</td>
<td>0.0864</td>
<td>0.0366</td>
<td>0.0726</td>
<td>0.0179</td>
</tr>
</tbody>
</table>

(4) Calculate the utility degree of the ideal and anti-ideal solution according to Equations (17) and (18). The results are shown in Table 6.

Table 6. Utility degree of the ideal and anti-ideal solution of various market-oriented business.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K(j)^+$</td>
<td>0.4566</td>
<td>0.5548</td>
<td>0.6886</td>
<td>0.7650</td>
<td>0.6646</td>
<td>0.4503</td>
<td>0.5679</td>
<td>0.5433</td>
</tr>
<tr>
<td>$K(j)^-$</td>
<td>1.2256</td>
<td>1.4890</td>
<td>1.8481</td>
<td>2.0532</td>
<td>1.7839</td>
<td>1.2085</td>
<td>1.5241</td>
<td>1.4582</td>
</tr>
</tbody>
</table>

(5) According to the utility degree of the ideal and anti-ideal solution in Table 6, the final utility function of market-oriented business regulatory risks is calculated according to Equations (19)–(21). The results are shown in Table 7.
Table 7. The final utility function of market-oriented business regulatory risks.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(K_j)$</td>
<td>0.6253</td>
<td>0.5157</td>
<td>0.4147</td>
<td>0.4089</td>
<td>0.4934</td>
<td>0.6947</td>
<td>0.5038</td>
<td>0.6036</td>
</tr>
</tbody>
</table>

As shown in Table 7, the regulatory risks of market-oriented business are ranked from large to small: $A6 > A1 > A8 > A2 > A7 > A5 > A3 > A4$. The comprehensive regulatory risk level of the A6 business may be the highest because of the poor performance in various risk dimensions. Except for the moderate performance in the security risk dimension, the performance of A6 in other risk dimensions is far worse than that of other businesses. In particular, for the most critical organizational isolation risk, A6 has the worst risk aversion ability. In contrast, although A4 is also not satisfactory in terms of organizational isolation, there is almost no risk situation in most other indicators. Hence, A4 ranks last in the overall regulatory risk ranking.

5. Comparison of the Results

In order to prove the superiority of the BBWM-MARCOS model proposed in this paper, two other MCDM models are compared in this section. Table 8 shows the models for ranking similarity comparison.

Table 8. The models for ranking similarity comparison.

<table>
<thead>
<tr>
<th>Models</th>
<th>Model Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>The proposed hybrid model based on BBWM and MARCOS</td>
</tr>
<tr>
<td>Model 2</td>
<td>The hybrid model based on BWM and MARCOS</td>
</tr>
<tr>
<td>Model 3</td>
<td>The hybrid model based on BBWM and TOPSIS</td>
</tr>
</tbody>
</table>

The comparison between Model 1 and Model 2 proves that the BBWM proposed in this paper is superior to the traditional BWM, and the comparison between Model 1 and Model 3 proves that the applied MARCOS approach is superior to the traditional TOPSIS.

5.1. Comparison of the Results of Model 1 and Model 2

According to the decision-making results, Table 9 lists the index weights determined by the five experts based on the traditional BWM.

Table 9. The indicator weights determined by five experts based on the traditional BWM.

<table>
<thead>
<tr>
<th>Experts</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0451</td>
<td>0.0789</td>
<td>0.3157</td>
<td>0.0631</td>
<td>0.0526</td>
<td>0.0395</td>
<td>0.0789</td>
<td>0.1578</td>
<td>0.1052</td>
<td>0.0631</td>
</tr>
<tr>
<td>2</td>
<td>0.0347</td>
<td>0.1020</td>
<td>0.3059</td>
<td>0.0612</td>
<td>0.0510</td>
<td>0.0437</td>
<td>0.1020</td>
<td>0.0765</td>
<td>0.1529</td>
<td>0.0612</td>
</tr>
<tr>
<td>3</td>
<td>0.0264</td>
<td>0.1983</td>
<td>0.1983</td>
<td>0.0616</td>
<td>0.0379</td>
<td>0.0236</td>
<td>0.2219</td>
<td>0.0852</td>
<td>0.1088</td>
<td>0.0379</td>
</tr>
<tr>
<td>4</td>
<td>0.0263</td>
<td>0.0949</td>
<td>0.1213</td>
<td>0.0686</td>
<td>0.0686</td>
<td>0.0295</td>
<td>0.0686</td>
<td>0.2210</td>
<td>0.2474</td>
<td>0.0537</td>
</tr>
<tr>
<td>5</td>
<td>0.0309</td>
<td>0.0882</td>
<td>0.2519</td>
<td>0.1501</td>
<td>0.0573</td>
<td>0.0519</td>
<td>0.0882</td>
<td>0.0882</td>
<td>0.1358</td>
<td>0.0573</td>
</tr>
<tr>
<td>Average</td>
<td>0.0345</td>
<td>0.1125</td>
<td>0.2386</td>
<td>0.0809</td>
<td>0.0535</td>
<td>0.0376</td>
<td>0.1119</td>
<td>0.1258</td>
<td>0.1500</td>
<td>0.0547</td>
</tr>
</tbody>
</table>

As can be seen from Table 9, due to the differences in the opinion preferences of the experts, the weights given by each expert are quite different. For instance, among the weight results given by Expert 1, the largest weight is 0.3157, and the smallest is only 0.0395. However, among the weight results given by Expert 3, the largest weight is 0.2219, whereas the smallest is 0.0264. Even if the weight scores of the experts are averaged, there is still a gap of more than 0.2 between the maximum and minimum weights finally provided.

The BBWM method proposed in this paper considers the group decision making of experts, which greatly reduces the heterogeneity between indicators and avoids the
situation where some indicators are extremely important and some indicators are almost useless. In contrast, the gap between the maximum and minimum weights calculated by BBWM is only 0.1254.

In addition, despite the introduction of Bayesian theory, the final weighting method does not change the importance ranking of indicators. This also proves that the BBWM method will not affect the opinions of experts by reducing the heterogeneity between indicators, which means important indicators retain their importance and unimportant indicators still maintain a lower weight.

Based on the weighting results of BWM, the MARCOS method is used to evaluate the regulatory risk of market-oriented businesses. The final risk utility function is shown in Table 10.

Table 10. Regulatory risk utility function of market-oriented business based on the BWM-MARCOS model.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f(K_j) )</td>
<td>0.6983</td>
<td>0.5118</td>
<td>0.5043</td>
<td>0.4148</td>
<td>0.4186</td>
<td>0.6137</td>
<td>0.5060</td>
<td>0.6117</td>
</tr>
</tbody>
</table>

The order of alternatives is: \( A_1 > A_6 > A_8 > A_2 > A_7 > A_3 > A_5 > A_4 \), which is a little different from the results given by the BBWM-MARCOS approach proposed in this paper. In contrast, the ranking of \( A_1 \) and \( A_6 \) has been adjusted, whereas the ranking of the other market-oriented business risks has not changed. The reason for this phenomenon is that the BWM method enlarges the heterogeneity between indicators, and important indicators become more important. Since \( A_1 \) has the highest risk on the C3 indicator, the overall risk of \( A_1 \) is further expanded, and surpasses that of \( A_6 \).

5.2. Comparison of the Results by Model 1 and Model 3

To prove the effectiveness of the MARCOS approach, TOPSIS was applied to rank the eight market-oriented businesses, as shown in Table 11.

Table 11. Regulatory risk utility function of market-oriented businesses based on BBWM-TOPSIS model.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation result</td>
<td>0.4248</td>
<td>0.2349</td>
<td>0.1577</td>
<td>0.0472</td>
<td>0.0505</td>
<td>0.7151</td>
<td>0.1899</td>
<td>0.3982</td>
</tr>
</tbody>
</table>

According to the closeness, the order is: \( A_6 > A_1 > A_8 > A_2 > A_7 > A_3 > A_5 > A_4 \). Except for the changes in the ranking of \( A_3 \) and \( A_5 \), the risk ranking of other businesses is consistent with the assessment results based on MARCOS.

In order to verify that the MARCOS approach proposed in this paper has better performance in ranking, this paper uses the index of sample separation to measure the ranking effect of each method. Standard deviation \( \sigma \), relative range \( \theta \), coefficient of variation \( \nu \), and sensitivity \( \eta \) are the most commonly used indicators to test the degree of sample separation. The formulas are as follows:

\[
\sigma = \sqrt{\frac{\sum_{j=1}^{m} (\delta_j - \bar{\delta})^2}{m}} \quad (22)
\]

\[
\theta = \frac{\delta_{j,\text{max}} - \delta_{j,\text{min}}}{\bar{\delta}} \times 100\% \quad (23)
\]

\[
\nu = \frac{\sigma}{\bar{\delta}} \quad (24)
\]

\[
\eta = \frac{\delta_{j,\text{max}} - \delta_{j,\text{sec}}}{\delta_{j,\text{max}}} \quad (25)
\]
where $\delta_j$ indicates the relative proximity of each evaluation object to the ideal solution, $\bar{\delta}$ represents the mean value of $\delta_j$, $\delta_{j_{\text{max}}}$ and $\delta_{j_{\text{min}}}$ respectively represent the maximum and minimum values of $\delta_j$, and $\delta_{j_{\text{sec}}}$ represents the second largest value of $\delta_j$. The above four indicators are all benefit indicators, which means that the larger the indicator value, the better the sample separation of the method.

The sample separation for TOPSIS and MARCOS methods is shown in Table 12.

### Table 12. The sample separation test indicators of the TOPSIS and MARCOS methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Sample Separation Test Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Deviation $\sigma$</td>
</tr>
<tr>
<td>TOPSIS</td>
<td>0.1361</td>
</tr>
<tr>
<td>MARCOS</td>
<td>0.1085</td>
</tr>
</tbody>
</table>

As shown in Table 12, MARCOS is slightly better than TOPSIS in all metrics except standard deviation, which also proves the superiority of the BBWM-MARCOS method proposed in this paper.

### 6. Conclusions

Power grid enterprises have always been supervised by multi-level government departments and various businesses, but focus more on risk prevention for regulated businesses. As a result of the continuous deepening of the reform for the power system, the government and industry have also paid more attention to the supervision of the market-oriented businesses for power grid enterprises. Therefore, it is necessary for power grid enterprises to strengthen the prevention of market-oriented business supervision risks. In this paper, a comprehensive regulatory risk assessment index system is proposed from four perspectives: policy risk, business isolation risk, market risk, safety risk. Then, the regulatory risk of market-oriented business for power grid enterprises is evaluated based on the BBWM and MARCOS approach. By comparing with the other two MCDM models, it was found that the BBWM-MARCOS model proposed in this paper can not only avoid the problem of large weight heterogeneity among indicators, but also improve the superiority of the scheme ranking. The evaluation shows that the BBWM-MARCOS method has good applicability for the market-oriented business supervision risk of power grid companies.

From the perspective of indicator weighting, the organizational isolation risk and market transaction risk are considered to be the most important indicators by most experts. This is because power grid enterprises need to pay attention to establishing functional departments responsible for market-oriented business alone, so as to avoid overlapping with regulated business departments. In addition, power grid enterprises need to pay attention to not abusing their dominant market position to disrupt market order and affect market transactions. In the pricing process, the power grid enterprises should also avoid price collusion, price discrimination, predatory pricing, and unfair pricing. Furthermore, the result is also consistent with the current government’s emphasis on the need for grid companies to clarify the boundaries of their market-oriented business and regulatory business, which also highlights the future development direction and the focus of supervision for power grid enterprises.

From the perspective of the evaluation results, the situation of various market-oriented businesses of the power grid enterprise is not optimistic. The A6 business faces relatively high regulatory risks, except for its moderate performance in terms of security. Therefore, the power grid enterprise needs to strengthen the management of the A6 business and improve the company’s risk prevention and control process. To this end, power grid enterprises need to build a closed-loop management and control mechanism for regulatory risk identification–assessment–early warning, which can help focus on key regulatory risks and enable targeted risk management measures to be taken.
In addition, there are also some disadvantages. From the methodological point of view, although the BBWM and MARCOS method proposed in this paper solves the limitations of traditional methods to a certain extent, it increases the complexity of the method, thus increasing the calculation process and time. In the future, more efficient and convenient methods will also be needed.

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**References**
