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Improved Calculation of Patent Sharing Rate Based on Entropy Weight-Grey Fuzzy Comprehensive Evaluation Model

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ABSTRACT

Under the background of optimizing intellectual property valuation systems, this study proposes an Entropy Weight-Grey Fuzzy Comprehensive Evaluation (GFCE) model to address data scarcity and indicator ambiguity in patent revenue-sharing rate calculations. A dual-dimensional index system (technology-market dimensions with 18 sub-indicators) integrates the Entropy Weight Method (EWM) for objective weighting and Grey Possibility Functions (Albino Weight Functions) to quantify fuzzy boundaries. Multi-angle sensitivity tests confirm the model's stability in patent valuation. Empirical analysis of 28 utility model patents from Hebei's AT enterprise demonstrates technical (0.42536) and market (0.57464) factor weights, with significantly improved revenue-sharing rates. Results validate the model's capability to assess patent maturity and market adaptability, offering a scientific framework for innovation resource optimization.

KEYWORDS

Patent value evaluation; Calculation of patent revenue sharing rate; Entropy weight-grey fuzzy comprehensive evaluation model; Sensitivity analysis

1 Introduction

The strategic value of patents has undergone multidimensional enhancement during the restructuring of the global intellectual property system. Data show patent grant growth rates consistently exceed trademarks/copyrights, solidifying patents as key indicators of national innovation efficacy[1]. As core vectors of technological innovation, synergistic improvements in patent quality and efficiency reflect innovation ecosystem optimization and drive market value conversion from legal rights[2]. Notably, China's 2023-2024 patent grants (Fig. 1(a)-(b)) demonstrate structural dominance: micro-level tech integration enhances corporate R&D efficiency and profit models, while macro-level innovation clustering deepens science-industry convergence[3-5]. This dual-drive mechanism highlights the urgency to develop precise patent valuation systems.

Current mainstream valuation methodologies include real options, portfolio evaluation, and intelligent optimization models[6]. Thoma G utilized the Tobin's q market value model to quantify the implied option premium within patent assets[7]; Grimaldi M developed the Patent Portfolio Value Index (PPVI) to establish a quantitative linkage between innovation levels and strategic decision-making[8-9]; Liu W expanded the modeling dimensions of patent valuation scenarios through heterogeneous data integration in probabilistic graph models[10]. Nevertheless, existing approaches exhibit limitations in handling data scarcity and quantifying indicator ambiguity.

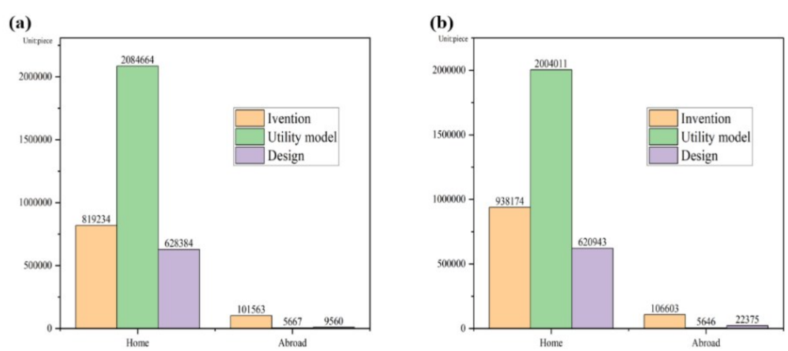

Fig. 1 Patent authorization at home and abroad from January to December (a)2023 and (b)2024

This study innovatively proposes an Entropy-Grey Fuzzy Comprehensive Evaluation model: First, it employs information entropy principles to decode the intrinsic structure of indicator data, achieving objective weighting via coefficient of variation analysis; Second, it integrates grey possibility functions with fuzzy membership calculations to construct a dual uncertainty processing mechanism; Finally, matrix-coupled operations enable precise measurement of revenue-sharing ratios. Empirical validation confirms that the model retains the logical rigor of Analytic Hierarchy Process (AHP) while effectively mitigating subjective cognitive biases and data stochasticity inherent in conventional evaluations, thereby advancing a novel methodological toolkit for valuing complex technological assets.

2 Research Framework and Methodology

This study constructs a patent value evaluation system following multi-dimensional principles (relevance, authenticity, typicality, operability), integrating market-technology dual dynamics under the Patent Value Analysis Index System framework. A longitudinal-horizontal quantitative model is established using entropy weight and grey-fuzzy methods to determine patent value, providing a structured framework for revenue-sharing rate calculations.

2.1 Construct the evaluation index system

This paper analyzes the factors affecting revenue sharing rate from two angles of technical factors and market factors, and gradually refines these two primary indicators into 18 specific secondary indicators, in order to comprehensively consider them from both quantitative and qualitative aspects. The evaluation index system constructed for this purpose is shown in the following table:

Table1 Index System of Revenue Share Rate Evaluation

Level 0	**Patent revenue sharing rate evaluation index system**	
Level 1	Technical Factor U_1	Market Factors U_2
Level 2	Advanced Technology V_{11}	Market Competition V_{21}
	Technology Alternative V_{12}	Market Risk V_{22}
	Technology Maturity V_{13}	Market Demand V_{23}
	Technical Confidentiality V_{14}	Market Application V_{24}
	Technical Scope of Application V_{15}	Market development difficulty V_{25}
	Technology independence V_{16}	Business Model Effectiveness V_{26}
	Development trend of technical field V_{17}	Product Pricing Right V_{27}
	Technological innovation V_{18}	Market Size and Potential V_{28}
	Technical standard V_{19}	Customer Loyalty V_{29}

2.2 Entropy weight method

The Entropy Weight Method (EWM) applies info-entropy principles: high-dispersion indicators yield lower entropy and higher discriminative power. EWM objectively weights via data dispersion analysis[11], reducing AHP's subjective bias. Its data-driven structure analysis auto-identifies key revenue-sharing factors, enhancing robustness[12].

(1) Standardized index data

Assuming that the initial matrix has m evaluation indicators an evaluation objects, the initial matrix can be expressed as:

$$X=(x_{ij})_{m\times n}=\begin{bmatrix} x_{11}\cdots x_{1n} \\ x_{21}\cdots x_{2n} \\ \vdots \quad \ddots \quad \vdots \\ x_{n1}\cdots x_{nn} \end{bmatrix} \tag{1}$$

After the initial matrix is standardized, $P=(P_{ij})_{m\times n}$ is obtained, wherein $P_{ij}(0\leqslant P_{ij}\leqslant 1)$ is the standard value of the j-th evaluation object on the i-th index.

When the index is proportional to the entropy value, that is, the higher the entropy value, the better the index:

$$p_{ij}=\frac{x_{ij}-min_j(x_{ij})}{max_j(x_{ij})-min_j(x_{ij})} \tag{2}$$

When the index is inversely proportional to the entropy value, that is, the smaller the entropy value, the better the index:

$$p_{ij}=\frac{max_j(x_{ij})-x_{ij}}{max_j(x_{ij})-min_j(x_{ij})} \tag{3}$$

(2) Calculate the entropy value of evaluation index

The entropy of index i is calculated as follows:

$$e_i=-k\sum_{j=1}^{n} z_{ij}lnn_{ij} \qquad (1\leqslant i\leqslant m) \tag{4}$$

In the formula, , $k=\frac{1}{lnn}$, when $z_{ij}=0$, can be specified $z_{ij}lnz_{ij} \;=\; 0$ at this time.

$$Z_{ij}=\frac{p_{ij}}{\sum_{j=1}^{n} p_{ij}}$$

(3) Calculate the entropy weight of evaluation index

The entropy weight of i index is calculated as follows:

$$w_i''=\frac{1-e_i}{\sum_{i=1}^{m}(1-e_i)} \;=\; \frac{1-e_i}{m-\sum_{i=1}^{m} e_i} \tag{5}$$

2.3 Grey fuzzy comprehensive evaluation method

The Grey-Fuzzy Evaluation Method (GFEM) combines fuzzy math (membership functions) and grey theory (AGO) to quantify qual. indicators and reduce data scarcity bias via grey relational analysis[13-14]. In patent valuation, GFEM employs Albino functions and grey relational degrees to replace subjective weighting, balancing cognitive-data balance for robust tech asset assessment.

The specific formula of grey fuzzy comprehensive evaluation method is as follows:

$$Q=R_i\times U_i\times A\times W^T \tag{6}$$

Where Q is the correction value of sharing rate, R_i is the grey evaluation weight matrix, U_i is the membership matrix of scheme layer, A is the comprehensive weight of criterion layer and W^T is the evaluation coefficient.

Wherein $R_i=\begin{bmatrix} r_{i1} \\ r_{i2} \\ \cdots \\ r_{ij} \end{bmatrix}$, the gray evaluation weight vector is $r_{ij}=(r_{ij1} \;\; r_{ij2} \;\; \cdots \;\; r_{ije})$ and the gray evaluation weight is $r_{ije}=\frac{\sum_{j=1}^{n} f_e(d_{ij})}{\sum_{e-1}^{S} c_{ije}}$, $f_e(d_{ij})$ is the gray possibility degree function corresponding to each gray class, d_{ij} is the evaluation of the j-th expert on the i-th secondary index, n is the number of experts participating in the scoring, e is the evaluation grade and c_{ije} is the gray evaluation coefficient.

3 Data and Research Scope

Hebei AT Corporation (est. 2004) specializes in thermal/new energy equipment and clean energy services, operating a full-industry chain from R&D to maintenance. Equipped with advanced production systems and provincial-certified patented technologies, its core products include environmental control systems. This study evaluates 28 valid utility model patents (as of October 31, 2024) with clear ownership, covering technical, legal, and economic aspects. Six experts conducted weighted scoring (indicator influence positively correlated with assigned scores) to complete the patent value assessment.

4 Results and Interpretation

4.1 Weight determination by entropy weight method

Using Table 2 data, normalization and entropy calculations derived difference coefficients, yielding entropy weights, visualized via pie chart.

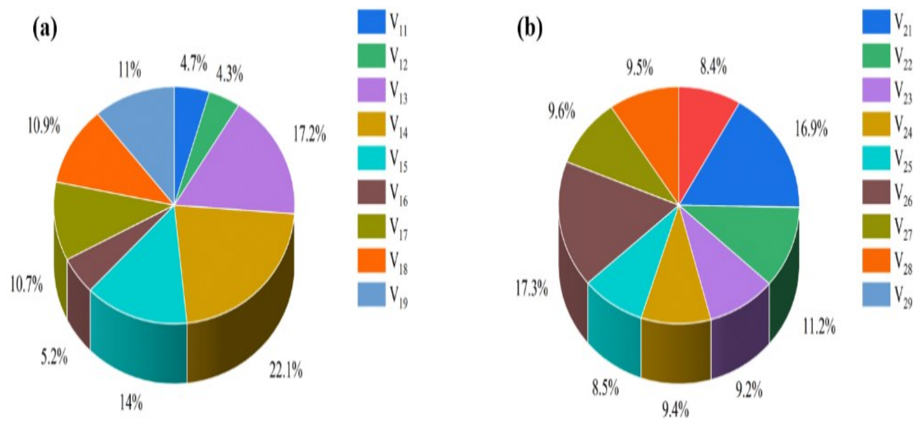

Fig. 2 Pie chart of weight distribution of V_{11}-V_{19} metrics under (a)U_1 and (b)U_2

Based on the calculation of the weight of the secondary indicators in the table, it can be calculated that the weights of the two primary indicators of technical factors and market factors are 0.4253491 and 0.5746509.

The final calculation results are shown in the following table:

Table 2 Entropy weight table of primary and secondary indicators

Level1 indicators	weight	Level2 indicators	weight
U1	0.42536	V11	0.02082
		V12	0.01899
		⋮	⋮
		V19	0.05074
U2	0.57465	V21	0.05007
		V22	0.09394
		⋮	⋮
		V29	0.06230

And the pie chart of the total weight results is shown in the following figure:

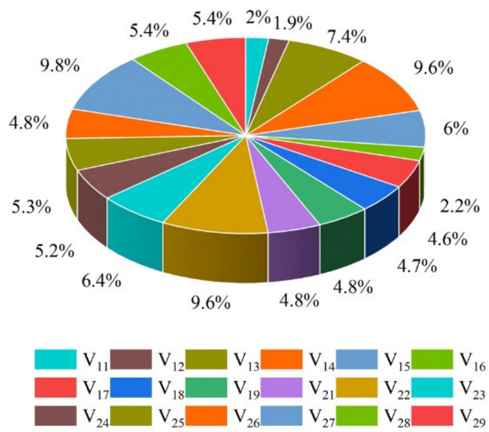

Fig. 3 Pie chart of weight distribution of V_{11}-V_{29} metrics under U_1 and U_2

4.2 Determining the Grey Simulation Evaluation Matrix

(1) The evaluation matrix is established based on the entropy weight method expert scoring. Six experts will continue to evaluate the patent under evaluation under various indicators. The higher the index level, the higher the score.

(2) Determine the evaluation grey coefficient

The gray number and whitening weight function of the 5 gray classes are as follows:

Class 1 is very good (e = 1):

Grey number: 1,5; Whitening weight function: f_1

$$f_1(d_{ij}^n) = \begin{cases} \frac{d_{ij}^n - 1}{4}, & if\ 1 \leqslant d_{ij}^n \leqslant 5 \\ 1, & if\ d_{ij}^n > 5 \\ 0, & if\ d_{ij}^n < 1 \end{cases} \tag{7}$$

Class 2 is good (e = 2):

Grey number: 0,4,7; Whitening weight function: f_2

$$f_2(d_{ij}^n) = \begin{cases} \frac{d_{ij}^n}{4}, & if\ 0 < d_{ij}^n \leqslant 4 \\ \frac{7 - d_{ij}^n}{3}, & if\ 4 < d_{ij}^n \leqslant 7 \\ 0, & if\ d_{ij}^n \leqslant 0\ or\ d_{ij}^n > 7 \end{cases} \tag{8}$$

Class 3 is medium (e = 3):

Grey number: 0,3,6; Whitening weight function: f_3

$$f_3(d_{ij}^n) = \begin{cases} \frac{d_{ij}^n}{3}, & if\ 0 < d_{ij}^n \leqslant 3 \\ \frac{6 - d_{ij}^n}{3}, & if\ 3 < d_{ij}^n \leqslant 6 \\ 0, & if\ d_{ij}^n \leqslant 0\ or\ d_{ij}^n > 6 \end{cases} \tag{9}$$

Class 4 is difference (e = 4):

Grey number: 0,2,5; Whitening weight function: f_4

$$f_4(d_{ij}^n) = \begin{cases} \frac{d_{ij}^n}{2}, & if\ 0 < d_{ij}^n \leqslant 2 \\ \frac{5 - d_{ij}^n}{3}, & if\ 2 < d_{ij}^n \leqslant 5 \\ 0, & if\ d_{ij}^n \leqslant 0\ or\ d_{ij}^n > 5 \end{cases} \tag{10}$$

Class 5 is very poor (e = 5):

Grey number: 0,1,3; Whitening weight function: f_5

$$f_5(d_{ij}^n) = \begin{cases} 1, & if\ 0 < d_{ij}^n \leqslant 1 \\ \dfrac{3-d_{ij}^n}{2}, & if\ 1 < d_{ij}^n \leqslant 3 \\ 0, & if\ d_{ij}^n \leqslant 0\ or\ d_{ij}^n > 3 \end{cases} \tag{11}$$

4.3 Calculation of grey evaluation coefficient

Then, the gray evaluation coefficient is calculated through the above-mentioned determined gray possibility function and the scores of six experts on the patented technology of Hebei AT enterprises.

4.4 Calculating the Grey Evaluation Weight Vector

Then, the grey evaluation coefficients are normalized, and the weights are determined by the ratio of each index coefficient to the total coefficient, and the grey evaluation weight vector table is constructed. The calculation results are shown in Table 3.

Table3 Table of Weight Vectors for Grey Evaluation of Indicators

	e=1	e=2	e=3	e=4	e=5
V11	0.28169	0.342723	0.250391	0.125196	0
V12	0.278816	0.343198	0.251298	0.126687	0
···	···	···	···	···	···
V18	0.334459	0.341216	0.22973	0.0945946	
V19	0.267913	0.325026	0.265836	0.141225	0
V21	0.272585	0.326371	0.263185	0.137859	0
V22	0.292366	0.317813	0.259881	0.12994	0
···	···	···	···	···	···
V28	0.261475	0.321815	0.270242	0.146467	0
V29	0.247972	0.317951	0.27789	0.156187	0

4.5 Obtaining Weight Vector (Membership Matrix)

Membership degrees are calculated by dividing index-specific gray coefficients by total evaluation coefficients, forming technical/market factor membership matrices.

$$S_1 = \begin{pmatrix} 0.028169 & 0.3427 & \cdots & 0 \\ 0.278816 & 0.343198 & \cdots & 0 \\ \vdots & \vdots & \vdots & 0 \\ 0.267913 & 0.325026 & \cdots & 0 \end{pmatrix} \tag{12}$$

$$S_2 = \begin{pmatrix} 0.272585 & 0.326371 & \cdots & 0 \\ 0.292366 & 0.317813 & \cdots & 0 \\ \vdots & \vdots & \vdots & 0 \\ 0.247972 & 0.317951 & \cdots & 0 \end{pmatrix} \tag{13}$$

4.6 Grey Fuzzy Comprehensive Evaluation

Firstly, carry out grey fuzzy comprehensive evaluation on 18 indicators at the scheme level, that is, multiply the membership matrix of each index with the corresponding weight matrix to obtain the grey fuzzy comprehensive evaluation result. If this result is Ui, then:

$$U_1 = (0.290897 \quad 0.329044 \quad 0.25424 \quad 0.125819 \quad 0) \tag{14}$$

$$U_2 = (0.282676 \quad 0.323967 \quad 0.260409 \quad 0.132947 \quad 0) \tag{15}$$

Then, the grey fuzzy comprehensive evaluation is carried out for the criterion layer:

$$V = A \times U = (0.286172 \ \ 0.326127 \ \ 0.257785 \ \ 0.129915 \ \ 0) \tag{16}$$

Calculation results indicate a 61.23% probability of the company's patented technology performing "good" or above. The gray fuzzy comprehensive evaluation vector is multiplied by the correction coefficient Q=3.768555 to derive the adjusted revenue-sharing rate:

$$\text{Revenue-sharing rate} = a\% \times 3.768555 \tag{17}$$

Post-correction analysis shows the revised revenue-sharing rate achieves balanced weight-enterprise dynamics alignment. The grey fuzzy method enhances practical relevance by accurately quantifying patent profitability contributions, ensuring tech-contextual balance (objective weighting & enterprise integration), validating patent value in real-world contexts.

5 Model testing

First, based on the weight perturbation sensitivity analysis in Figure 4, the fluctuation range of the total correlation score is only 1.6% (0.5800-0.5893) under the ±10% weight adjustment, indicating that the model has low sensitivity to weight changes.

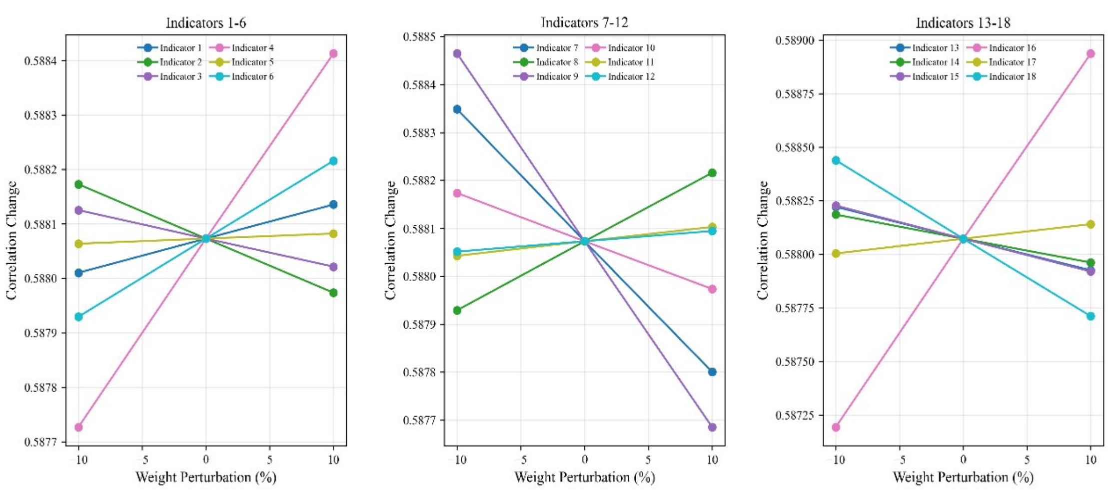

Fig. 4 Weight Perturbation Sensitivity Analysis

Secondly, the sensitivity ranking results in Figure 5 show that indicators 16 (technology maturity), 9 (market penetration) and 18 (patent implementation risk) have the most significant impact on the revenue sharing ratio (maximum deviation of 0.0008).

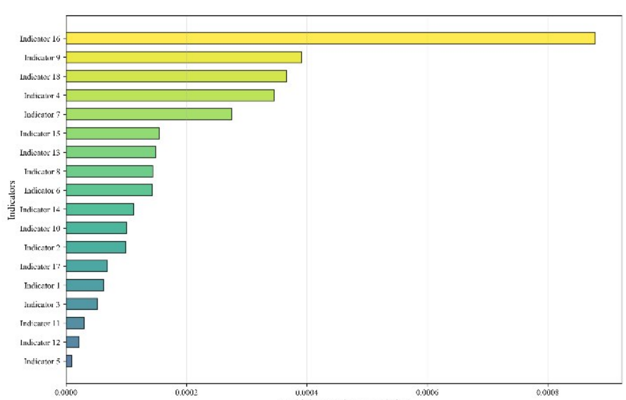

Fig. 5 Sensitivity Ranking Analysis

Tests confirm the grey model distinguishes ρ =0.5 from theoretical optima, achieving "high stability-moderate sensitivity" Pareto equilibrium at the sensitivity-convergence phase transition. Robustness under param. perturbation, fuzzy metrics, and data scarcity validates reliable patent valuation.

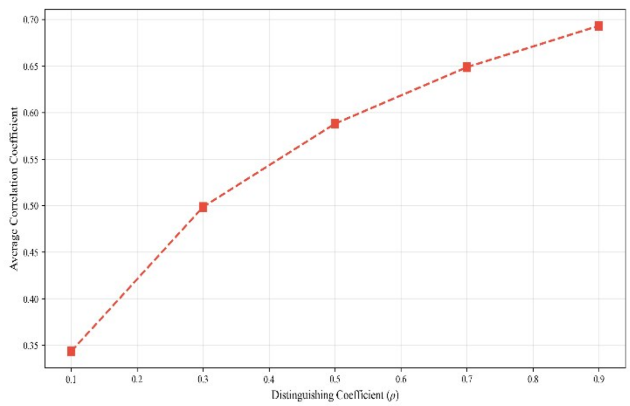

Fig. 6 ρ Parameter Sensitivity Analysis

6 Conclusion

This study innovates dual-parameter optimization within the income method framework by constructing a technology-market dual-dimensional index system to overcome traditional parameter rigidity. A hybrid Delphi-entropy weight mechanism balances expert insights and data-driven analysis, while a grey-fuzzy model with whitening functions quantifies implicit value by extracting patent lifecycle features and resolving expert ambiguity via triangular fuzzy processing. Sensitivity tests confirm the model's stability in patent valuation, enhancing accuracy in assessing technical maturity and market adaptability.

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