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# The Quantitative Analysis and Decision-making of MSMEs' Credit Risk

**Xiaorui Tao[1*], Junzhe Zhao[1], Jianying Xu[1], Keyue Wang[1]**

[1]College of Economics & Management, China Three Gorges University, Yichang, 443002, China.

**ABSTRACT**

In this study, we focused on the quantitative analysis and decision-making of credit risk of the Micro, Small and Medium Enterprises (MSMEs) from the perspective of bank. Based on the data of 123 MSMEs, we extracted and processed information from the original data with theoretical analysis and feature engineering, and established an entropy weight-TOPSIS model to get the credit risk index of each MSME. Meanwhile, the credit strategy optimization model was constructed, and the DE algorithm was used to solve the credit strategy scheme for bank to each MSME. According to the relationship between the total annual credit of bank, interest rate and expected profit, we analyzed the partial sensitivity of the model and explored the maximum profitability of the bank and finally gave helpful suggestions. Our results have guiding significance for banks to manage and make decisions on the credit risk of MSMEs.

**Keywords:** Credit risk; MSMEs; Entropy weight-TOPSIS model; Credit strategy optimization model; DE algorithm

***Correspondence to Author:**
Xiaorui Tao
College of Economics & Management, China Three Gorges University, Yichang, 443002, China.

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## 1. Introduction

With the continuous development of market economy, the most active MSMEs in the market became to the primary driving force of China's economic development for their outstanding degree of activity and development. However, the financing problem is the biggest bottleneck for the development of MSMEs [1].

The main source of funds for MSMEs in China is bank loans, which generally difficult for MSMEs because of their low credibility and repayment ability. At present, an effective risk measurement and lending mechanism haven't been constructed for MSMEs. Banks cannot effectively distinguish the advantages and disadvantages of MSMEs and the size of their risks to make financing decisions and scientific loan plans for MSMEs, and this difficult loan situation of MSMEs has not been improved for a long time. Thus it is necessary to establish a reasonable credit risk evaluation system for MSMEs and help banks to formulate appropriate credit programs.

Armendariz et al.[2] analyzed the risk factors of microfinance and concluded that the risk concentration should be used as an important index to evaluate the credit risk of MSMEs. Zhang et al.[3] selected 164 MSMEs as samples, and conbined the method of factor analysis and Logist regression analysis to establish a credit risk measurement model for MSMEs. Cui et al.[4] summarized the risk prevention and control measures of international advanced banks in MSMEs, including access system, quota system, second repayment source system, credit risk rating system, closed bank-enterprise business cooperation and other management tools, credit authorization approval process, loan pricing system and other management mechanisms. Ge et al.[5] showed that there is a significant correlation between macroeconomic operation, the scale, the personal characteristics of business owners, the financial status and loan risk of MSMEs.

Most of these studies have analyzed the risk management of MSMEs from the perspectives of risk identification, risk early warning, risk disposal and other management flows. This paper draws lessons from these analysis angles and methods, studies quantitative analysis to the data of MSMEs, establishes the entropy weight-TOPSIS model to quantify the credit risk, and then constructs the credit strategy optimization model based on differential evolution algorithm. Finally, it gives relevant suggestions based on the sensitivity analysis.

## 2. Selection, construction and calculation of indexs

The credit risk is evaluated according to the probability that the default of enterprise during the credit activities and the severity of the loss that the default may ceause. To judge the credit situation of a MSME, we need to focus on aspects of the internal and external factors of the enterprise, including financial indicators, business prospects, comprehensive strength and so on. Aiming at the credit risk rating of MSMEs, this paper has considered the following aspects.

### 2.1 Comprehensive strength of MSMEs $U_1$

The comprehensive strength of the enterprise mainly analyzes the basic economy, influence and stability of the enterprise. The of a MSME can directly reflect its loan repayment ability, and the main basic indicators of comprehensive strength are the annual operating profit of MSMEs $\mu_1$, the influence of upstream $\mu_2$ and downstream MSMEs and the stability of supply and demand $\mu_3$.

#### 2.1.1 Annual operating profit $u_1$

The most direct manifestation of the operating benefit of the enterprise is the operating profit. Then the annual operating profit of the i-th MSME is:

$$u_{1\mathrm{i}}=\frac{s_{2_\mathrm{i}}-s_{1\mathrm{i}}}{365} \quad (1)$$

Where $s_{2_\mathrm{i}}$ is the total output amount of the i-th MSME without tax and $s_{1\mathrm{i}}$ is the total input amount of the i-th MSME without tax.

#### 2.1.2 The influence of upstream and downstream MSMEs $u_2$

In the evaluation process of comprehensive strength, the influence of upstream and downstream MSMEs should to be taken into consideration[5]. Then the upstream and downstream influence of the i-th MSME is：

$$u_{2\mathrm{i}}=\frac{1}{2}\frac{c_{2\mathrm{i}}+c_{2\mathrm{i}}}{365} \quad (2)$$

Where $c_{1\mathrm{i}}$ is the total transaction amount between the i-th MSME and the i-th upstream MSME, and $c_{2\mathrm{i}}$ is the total transaction amount between the i-th MSME and the i-th downstream MSME.

### 2.1.3 Stability of supply and demand relationship *u*3

The supply and demand relationship of enterprise management can affect the stable cooperative relationship between MSMEs, suppliers and consumers. We compare and calculate the stability of supply and demand relationship of each MSME through coefficient of variation, and select the standard deviation coefficient and that is:

$$V\sigma_{\mathrm{i}1}=\frac{\sigma_1}{\widehat{\mathrm{X}_1}}\times 100\% \quad (3)$$

Where $V\sigma_{\mathrm{i}1}$ is the coefficient of variation of the input standard deviation of the i-th MSME, $\sigma_1$ is the standard deviation of the input amount, and $\widehat{\mathrm{X}_1}$ is the average of the input amount.

$$V\sigma_{\mathrm{i}2}=\frac{\sigma_2}{\widehat{\mathrm{X}_2}}\times 100\% \quad (4)$$

Where $V\sigma_{\mathrm{i}2}$ is the coefficient of variation of the standard deviation of the output amount of the i-th MSME; $\sigma_2$ is the standard deviation of the output amount; $\widehat{\mathrm{X}_2}$ is the average amount of the output amount.

Then the coefficient of variation of the standard deviation of the i-th MSME is:

$$V\sigma_{\mathrm{i}}=\frac{1}{2}(V\sigma_{\mathrm{i}1}+V\sigma_{\mathrm{i}2}) \quad (5)$$

Convert it into large data, and the stability of the supply and demand relationship is:

$$u_3=\max(V\sigma_{\mathrm{i}})\text{-}V\sigma_{\mathrm{i}} \quad (6)$$

Where $\max(V\sigma_{\mathrm{i}})$ is the largest coefficient of variation among n MSMEs.

### 2.2 Enterprise reputation rating *U*2

**Credit rating $\mu_4$:** According to the data of 123 MSMEs with credit records and 302 MSMEs without credit records[6], the credit rating of MSMEs is divided into four grades(A, B, C, D), which can show the basic creditibility of MSMEs. At the same time, MSMEs with credit grade of D usually are not allowed to lend.

### 2.3 Enterprise management ability *U*3

The management ability of an enterprise is reflected in the comprehensive quality of the enterprise, including historical performance and daily business transactions, which can reflect the willingness and ability of the MSME to repay the loan. The main indicators of management ability are the annual breach of contract $u_5$, the number of negative invoices $u_6$ and the number of invalid invoices $\mu_7$.

### 2.4 Feature engineering

Since the huge amount of data, it may lose meaningful information if we only combine the comprehensive strength and the reputation rating of the MSME. Therefore, this paper constructs the characteristics of the annual operating profit, the influence of upstream and downstream MSMEs and the stability of supply and demand to assess the comprehensive strength.

Under the premise of data normalization, considering that the data is a single table and the primary key of the table is the enterprise number, we can use Python Featuretools library to perform a conversion operation on the single table based on index transformation, and create a new feature $u_8$,$u_9$,$u_{10}$ from three existing columns, namely, the annual operating profit $u_1$

of MSME, the influence $u_2$ of the upstream and downstream MSMEs, and the stability $u_3$ of supply and demand, as shown in Fig. 1.

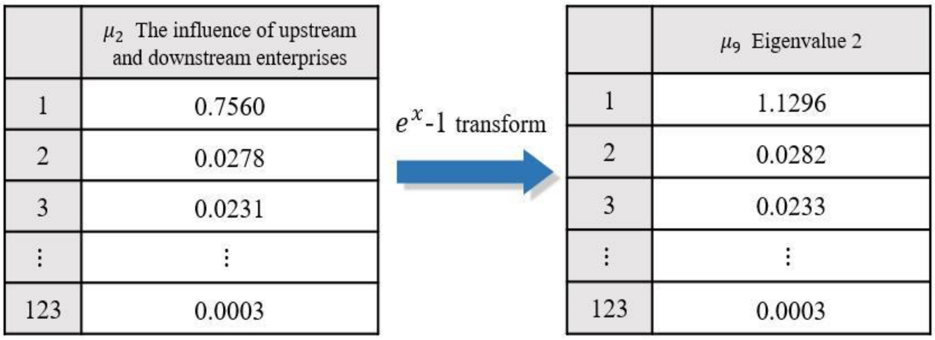


**Fig. 1  The diagram of exponential transformation process**

That is:

$$u_k = e^{u_i} - 1 \tag{1}$$

Where $k$=8,9,10; $i$=1,2,3, and $k$ corresponds to $i$ one by one.

In summary, the 4 first-level indicators and 10 second-level indicators were constructed and their relationships are shown in Fig. 2:

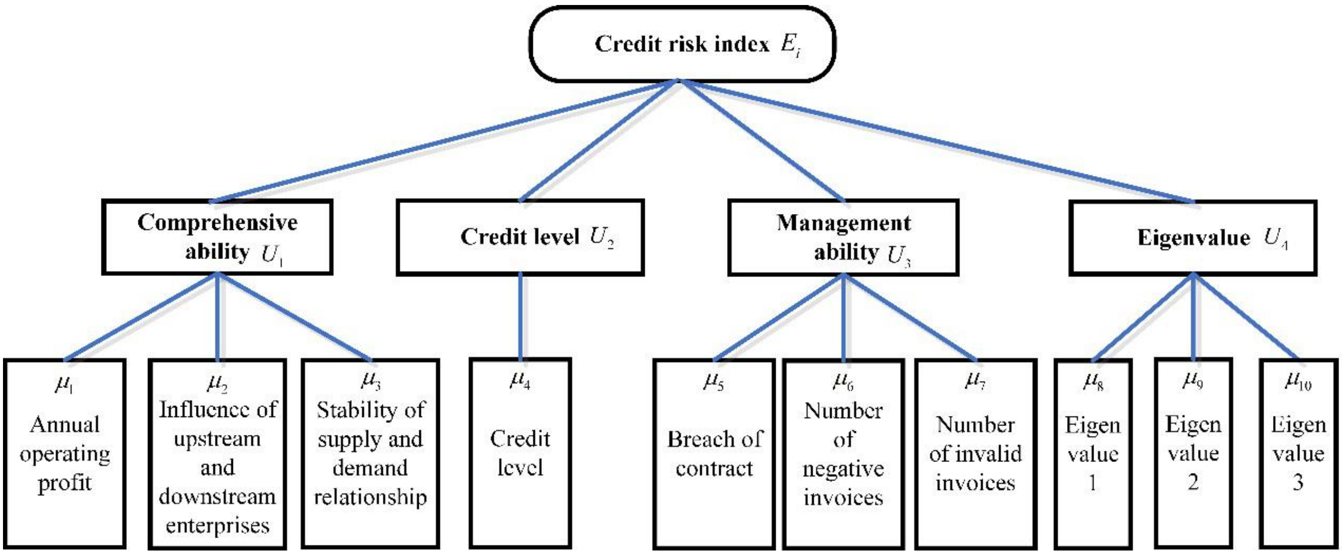


**Fig. 2  Multi-level index system**

## 3. Entropy weight-TOPSIS model

The distance method of good-bad solutions (TOPSIS) is a sort method that approximates the ideal solution, which can well describe the strength of many influence indexes and suitable for the credit risk evaluation system. Entropy weight method is an objective weighting method, which can use information entropy to calculate the weight of each index and provide a basis for multi-level comprehensive evaluation. In this paper, the specific calculation steps for the first-level indicators are as follows:

### 3.1 Determination of the evaluation matrix

An evaluation matrix $R$ with $n$ rows and $m$ columns is constructed, and the element $r$ in the matrix represents the index value of the corresponding the i-th MSME under the j-th index. Here, $n=123$, $m=10$, $i=1,2,\cdots,n$, $j=1,2,\cdots,m$, then $R$ is:

$$R = [r_{ij}] = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (1)$$

### 3.2 Positivism and standardization

For the positive consistency of data, we deal with the instability of the relationship between supply and demand, the number of negative invoices and invalid invoices, and that is:

$$r_{ij}^{(1)} = \max(r_{ij}) - r_{ij} \quad (1)$$

Where $\max(r_{ij})$ is the maximum value in the j-th index data, $r_{ij}$ is the corresponding value of the i-th MSME under the j-th index before the positivization, and $r_{ij}^{(1)}$ is the corresponding value of the i-th MSME under the j-th index after the positivization.

For the standardization of data, we use the calculation formula of matrix standardization to standardize the positive data in order to eliminate the influence of different index dimensions on the model, that is:

$$z\ 2 = \frac{r_{ij}^{(1)}}{\sqrt{\sum_{i=1}^{n} {r_{ij}^{(1)}}^2}} \quad (2)$$

### 3.3 Determination of weight by the entropy method

In this paper, each index is weighted and reprocessed by introducing entropy method. The probability matrix is set as each element $p_{ij}$ in gpencil $P$ to represent the proportion of the first MSME under the j-th index, which is regarded as the probability used in the calculation of relative entropy. The calculation formula is as follows:

$$p_{ij} = \frac{p_{ij}}{\sum_{i=1}^{n} p_{ij}} \quad (1)$$

Where $i=1,2,\cdots,n;\ j=1,2,\cdots,m$

The information entropy $e_j$ of each index is calculated, and the information utility value $d_j$ is calculated, and the entropy weight $a_j$ of each index is normalized, that is:

$$e_j = -\frac{1}{\ln 123} \sum_{i=1}^{123} p_{ij} \ln(p_{ij}) \quad (2)$$

$$d_j = 1 - e_j \quad (3)$$

$$A_j = \frac{d_j}{\sum_{j=1}^{m} d_j} = [a_1, a_1, \cdots, a_j, \cdots, a_m] \quad (4)$$

### 3.4 TOPSIS method

Set the decision matrix to Z, that is:

$$Z = [z_{ij}] = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{bmatrix} \quad (1)$$

Where $z_{ij}$ represents the positive and standardized value of the i-th MSME under the j-th index.

Define maximum:

$$Z^+ = (Z_1^+, Z_2^+, \cdots, Z_m^+) = (\max\{z_{11}, z_{21}, \cdots, z_{n1}\}, \max\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, \max\{z_{1m}, z_{2m}, \cdots, z_{nm}\})$$

Define minimum: $Z^- = (Z_1^-, Z_2^-, \cdots, Z_m^-) = (\min\{z_{11}, z_{21}, \cdots, z_{n1}\}, \min\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, \min\{z_{1m}, z_{2m}, \cdots, z_{nm}\})$

Define the distance between the x-th MSME and the maximum $D_i^- = \sqrt{\sum_{j=1}^{m} A_j \left(Z_j^- - z_{ij}\right)^2}$

The unnormalized score $S_i$ of the x-th MSME can be calculated, that is:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{2}$$

Then the normalized score $\widehat{S}_i^{(1)}$ is:

$$\widehat{S}_i^{(1)} = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{3}$$

And the comprehensive evaluation of the first-level indicators was finished.

Similarly, we can calculate the weight $a_1'$,$a_2'$,$a_3'$,$a_4'$ of the second index and the final normalized score $\widehat{S}_i^{(2)}$, complete the comprehensive evaluation of the secondary index and get the final target index $E_i$ and that is the MSME's credit risk index, and convert it into data that the higher the value represents the higher the risk.

**4. Grade classification of credit risk index**

According to the characteristic that the number of MSMEs in each credit risk grade approximately obeys the normal distribution[7], and combined with the sample proportion of MSME in each grade, the corresponding credit risk index interval of MSME in each grade is determined. The MSME whose credit risk index belongs to a certain range is planned to be the grade of this interval. It can be divided into nine credit risk grades, which are AAA,AA,A,BBB, BB,B,CCC,CC,C, and its three major grades are A, B, C. The proportion, cumulative proportion and explanation of each grade are shown in Table 1.

**Table 1 Enterprise credit risk rating standard table**

| Credit risk level | Sample proportion (%) | Cumulative proportion (%) | The degree of credit | Explanation |
|---|---|---|---|---|
| AAA | 6% | 6% | The best | |
| AA | 18% | 24% | Excellent | Good credit, small credit risk and strong repayment ability |
| A | 30% | 54% | Great | |
| BBB | 16% | 70% | Good | |
| BB | 11% | 80% | Normal | Good credit, normal credit risk, need effective guarantee to avoid risk |
| B | 8% | 89% | Little poor | |
| CCC | 6% | 94% | Poor | |
| CC | 4% | 98% | Very poor | Poor credit, high credit risk, need measures to improve repayment ability |
| C | 2% | 100% | The worst | |

As can be seen from the Table 1, MSMEs from the best credit to the worst are divided into nine grades AAA to C. The overall credit risk of A-level MSMEs is small, so banks may give them hte loans with longer term and larger amount, and msot interest rate concessions; The B-level MSMEs have a certain credit risk, banks may give them moderate amount of credit term and limited interest rate concessions. The C-level MSMEs is poor and the credit risk is high, so banks may give a small amount of loan with strict conditions or not at all. The probability distribution of the credit ratings of 123 MSMEs are shown in Fig. 3:

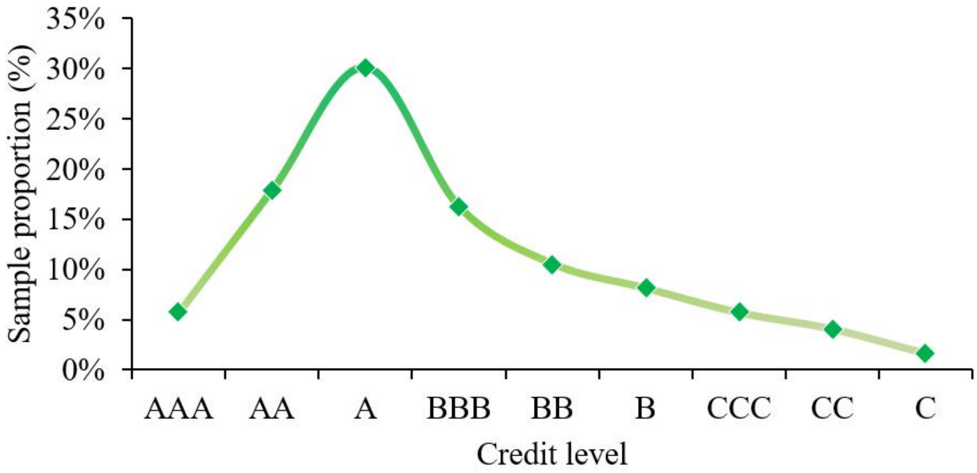


**Fig. 3 The probability distribution map of credit rating of 123 MSMEs**

As shown in Fig. 3, the rating classification of the credit risk index conforms to the normal distribution characteristic of big in the middle and small at the two ends, which ensures that 50% of the rating samples are gathered near A and BBB. It can avoid the unreasonable phenomenon that most MSMEs gather near AAA or C and also make up for the lack of subjective determination in the existing credit risk classification.

## 5. Credit strategy optimization model

Set the annual interest rate of the bank loan of the i-th MSME as $p_{\mathrm{i}}, p_{\mathrm{i}} \in [0.04, 0.15]$ ; set the amount of the loan of the i-th MSME as $q_{\mathrm{i}}$ and $q_{\mathrm{i}} \in [10, 100]$, and its unit is ten thousand yuan; set the term of the i-th MSME as $t_{\mathrm{i}}$, and $t_{\mathrm{i}} \in [0,1]$, and its unit is year; set the customer turnover rate of the i-th MSME as $l_{\mathrm{i}}$. The strategies are discussed respectively as follows.

### 5.1 Whether or not lending strategy

According to the relationship between the credit rating and the annual interest rate of bank loans, the MSME with credit rating D of 123 MSMEs is not allowed to borrow, while others are available.

### 5.2 Loan quota allocation strategy

According to the strategy of loan line allocation, the loan line allocation is considered on the basis of each MSME credit risk index, that is, the loan line is divided into 9 segments according to the MSME credit risk index, such as the credit rating AAA is divided into the first paragraph [90,100], and its unit is ten thousand. Then, through the median judgment, the segmentation is further optimized, that is:

$$q_{\mathrm{i}} = \begin{cases} q_{\mathrm{i}}[1+0.2(1\text{-}E_{\mathrm{i}})],\ E_{\mathrm{i}} \le M \\ q_{\mathrm{i}}(1\text{-}0.2E_{\mathrm{i}}),\ q_{\mathrm{i}} > M \end{cases},\ i = 1, 2, \cdots, \mathrm{n} \qquad (1)$$

Where $M$ is the median of the credit risk index of all n MSMEs.

### 5.3 Annual interest rate allocation strategy

According to the interest rate allocation strategy, consider the credit risk index of each MSME, and judge the median, that is:

$$p_{\mathrm{i}} = \begin{cases} p_{\mathrm{i}}[1\text{-}0.1(1\text{-}E_{\mathrm{i}})],\ E_{\mathrm{i}} \le M \\ p_{\mathrm{i}},\ E_{\mathrm{i}} > M \end{cases},\ i = 1, 2, \cdots, \mathrm{n} \qquad (1)$$

Considering the relationship between the annual interest rate of bank loans and customer turnover rate, combined with the data analysis of the three fourth power fitting curves in the data analysis constraints, that is:

$$\begin{cases} l_A(p_i)=-5095p_i^4+2574p_i^3-519.3p_i^2+52.6p_i \\ l_B(p_i)=-5963p_i^4+2815p_i^3-530.2p_i^2+51.17p_i-1.354 \\ l_c(p_i)=-2202p_i^4+1340p_i^3-320.1p_i^2+38.5p_i-1.098 \end{cases} \quad (2)$$

### 5.4 Term allocation strategy

In view of the term allocation strategy, taking into account the phenomenon of bank bad debts, such as overdue loans, sluggish loans, bad debt loans, etc. The bad debt rate variable $k$ is introduced and that is the more bad debts occur, the greater the $k$ value, and the shorter the term of the loan. According to historical data[8], the bank bad debt rate is generally between 5% and 10%, that is:

$$k=1-(0.05+0.05t) \quad (1)$$

### 5.5 Credit strategy optimization model

The fundamental purpose of the teammate lending strategy is to maximize the expected profit $W_1$ of each MSME, and consider the influence of the bad debt rate variable $k$ to follow the exponential law, we set the objective function as:

$$\max W_1=q_i p_i t_i(1-l_i)[ke^{1.5+E_i}] \quad (1)$$

At the same time, factors such as lending, loan quota, interest rate and term should be taken into account, that is, on the premise of excluding credit rating $D$, combined with the above allocation strategy, the following constraints are given:

$$s.t.\begin{cases} q_i=\begin{cases} q_i[1+0.2(1-E_i)], E_i\le M \\ q_i(1-0.2E_i), q_i>M \end{cases}, i=1,2,\cdots,n \\ p_i=\begin{cases} p_i[1-0.1(1-E_i)], E_i\le M \\ p_i, E_i>M \end{cases}, i=1,2,\cdots,n \\ l_A(p_i)=-5095p_i^4+2574p_i^3-519.3p_i^2+52.6p_i \\ l_B(p_i)=-5963p_i^4+2815p_i^3-530.2p_i^2+51.17p_i-1.354 \\ l_c(p_i)=-2202p_i^4+1340p_i^3-320.1p_i^2+38.5p_i-1.098 \\ k=1-(0.05+0.05t) \\ q_i\in[10,100] \\ p_i\in[0.04,0.15] \\ t_i\in[0,1] \end{cases} \quad (2)$$

## 6. Differential evolution algorithm

Differential evolution (DE) algorithm[9] is an efficient global optimization algorithm. Differential evolution is a population-based heuristic search algorithm in which each individual in the population corresponds to a solution vector. Compared with other genetic algorithms, differential evolution algorithm has the advantages of simple execution, fast convergence and good global search performance. Based on the above characteristics, differential evolution algorithms are often used to solve constrained optimization problems. In this paper, differential evolution algorithm is used to solve the above model, and the specific operations are as follows:

### 6.1 Population Initialization

A population containing NP individuals is defined. Each individual in the population can be represented by a D-dimensional parameter vector, and a single individual can be expressed as $X_{i,G}(i=1,2,\cdots,NP)$, where G is the algebra of the current population and $i$ is the i-th individual in the population.

In order to ensure the smooth follow-up processing, the current population needs to be initialized. In this paper, we choose the most common method to obtain the initial population, that is, random selection within the boundary constraints. Let $U$ and $L$ be the upper bound and the lower bound of each dimension of the individual, that is, the range of the initial population is $(X_{i,G}^{L}, X_{i,G}^{U})$ . Assuming that all random populations are uniformly distributed, the initial population is obtained by:

$$X_{ij}=\text{rand}[0,1]\times\left(X_j^U\text{-}X_j^L\right)+X_j^L \tag{1}$$

Where rand is a random function, and take the random number between 0 and 1.

**6.2 Variation**

For the DE algorithm, the common difference strategy is to randomly select two different individuals in the population, and then add the vector difference scaling to another vector in the population that is different from the currently selected vector, and then get the variation variable. The execution flow of the difference mutation is shown in Fig. 4:

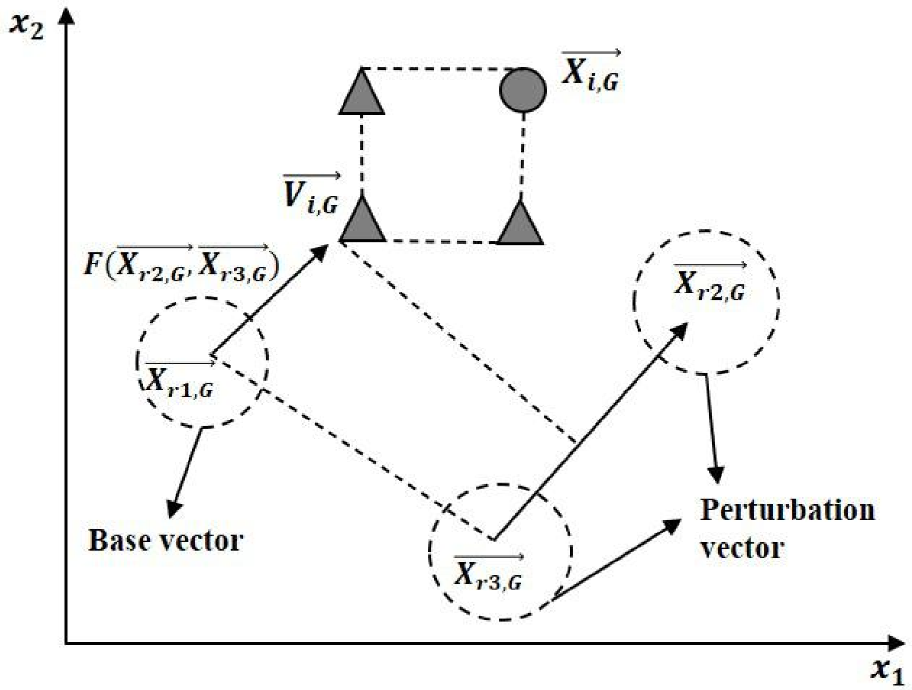


**Fig. 4 The diagram of differential mutation operation**

That is:

$$V_i(g+1)=X_{r1}(g)+F(X_{r2}(g)\text{-}X_{r3}(g)) \tag{1}$$

Where $r_1, r_2, r_3$ is three different random numbers, the interval is $[1, NP]$, and $F$ ($F\in[0,2]$) is the rotation factor, which is a definite real constant factor and its function is to control the deviation of magnification and reduction of variables, and $g$ is the evolutionary algebra.

**6.3 Cross**

The purpose of crossover operation is to select individuals randomly. In this paper, binomial crossover strategy is adopted to obtain the attempt vector $U_i$, that is:

$$U_{ij,G}=\begin{cases}V_{ij,G},\ \text{rand}(0,1)\le CR \text{ or } j=j_{\text{rand}}\\ X_{ij,G},\ \text{otherwise}\end{cases} \tag{1}$$

Where $U_{ij,G}$ is the attempt vector; $V_{ij,G}$ represents the value on the j dimension corresponding to the target vector; $X_{ij,G}$ is also the value on the j dimension corresponding to the target vector; $\text{rand}(0,1)$ is a random number that satisfies the uniformly distributed distribution between 0 and 1; $CR$ is the crossover probability, and this paper takes 0.5; $j_{\text{rand}}$ as a random integer between 1 and D; $x_{i,G}=\{x_{1i,G},x_{2i,G},\cdots,x_{Di,G}\}$ is the target vector, and its specific operation is shown in Fig. 5:

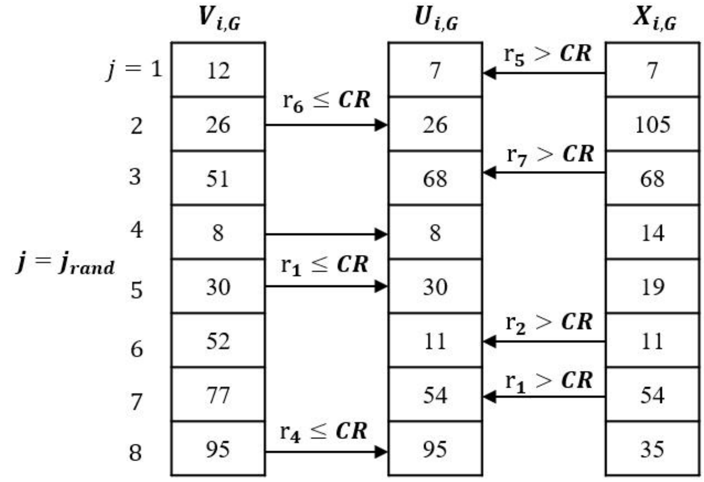


**Fig. 5 Binomial crossover operation**

### 6.4 Selection

For the DE algorithm, the greedy selection strategy is adopted, and the individuals entering the next generation population can be determined according to the objective function values of the attempt vector $U$ and the target vector $X$, and the way to obtain it is as follows:

$$U_{\mathrm{i,G+1}}=\begin{cases}U_{\mathrm{i,G}},\ f\left(U_{\mathrm{i,G}}\right)<f(X_{\mathrm{i,G}})\\ X_{\mathrm{i,G}},\ \text{otherwise}\end{cases} \qquad (1)$$

Where $U_{\mathrm{i,G+1}}$ is the individual vector entering the next generation population and $f$ is the objective function value.

### 6.5 Credit Strategy Optimization Model based on differential Evolution

Combined with the basis of the credit strategy optimization model, that is:

$$\min W_1=q_{\mathrm{i}}p_{\mathrm{i}}t_{\mathrm{i}}(1\text{-}l_{\mathrm{i}})[ke^{1.5+E_{\mathrm{i}}}] \qquad (1)$$

$$s.t.\begin{cases}q_{\mathrm{i}}=\begin{cases}q_{\mathrm{i}}[1+0.2(1\text{-}E_{\mathrm{i}})],E_{\mathrm{i}}\leq M\\ q_{\mathrm{i}}(1\text{-}0.2E_{\mathrm{i}}),q_{\mathrm{i}}>M\end{cases},i=1,2,\cdots,\mathrm{n}\\ p_{\mathrm{i}}=\begin{cases}p_{\mathrm{i}}[1\text{-}0.1(1\text{-}E_{\mathrm{i}})],E_{\mathrm{i}}\leq M\\ p_{\mathrm{i}},E_{\mathrm{i}}>M\end{cases},\mathrm{i}=1,2,\cdots,\mathrm{n}\\ l_{\mathrm{A}}(\mathrm{p_i})=\text{-}5095p_{\mathrm{i}}^4+2574p_{\mathrm{i}}^3\text{-}519.3p_{\mathrm{i}}^2+52.6p_{\mathrm{i}}\\ l_{\mathrm{B}}(\mathrm{p_i})=\text{-}5963p_{\mathrm{i}}^4+2815p_{\mathrm{i}}^3\text{-}530.2p_{\mathrm{i}}^2+51.17p_{\mathrm{i}}\text{-}1.354\\ l_{\mathrm{c}}(\mathrm{p_i})=\text{-}2202p_{\mathrm{i}}^4+1340p_{\mathrm{i}}^3\text{-}320.1p_{\mathrm{i}}^2+38.5p_{\mathrm{i}}\text{-}1.098\\ k=1\text{-}(0.05+0.05t)\\ q_{\mathrm{i}}\in[10,100]\\ p_{\mathrm{i}}\in[0.04,0.15]\\ t_{\mathrm{i}}\in[0,1]\end{cases} \qquad (2)$$

Carry out a series of operations such as mutation, crossover, selection to obtain the variation vector and attempt vector, and then obtain the optimal solution.

Through the entropy weight-TOPSIS method, the credit strategy optimization model based on differential evolution algorithm and the corresponding steps by Python, the credit risk index and credit strategy of each MSME can be obtained under the condition that the total annual credit is fixed. The results are shown in Table 2:

**Table 2 The results of credit strategies of 123 MSMEs**

| MSMEs code | Credit level | Risk factor | Risk level | Amount (¥W) | Interest rate (%) | Loan term (yr) | Expected income (¥W) |
|---|---|---|---|---|---|---|---|
| E1 | A | 0.2445 | AAA | 100.0000 | 4.4644 | 1.00 | 4.4644 |
| E2 | A | 0.6477 | AA | 96.3408 | 4.4644 | 0.67 | 2.8709 |
| E3 | C | 0.5652 | AAA | 100.0000 | 5.3246 | 0.77 | 4.0892 |
| E4 | C | 0.0000 | AAA | 100.0000 | 5.3246 | 1.00 | 5.3246 |
| E5 | B | 0.6493 | AA | 96.3121 | 4.9412 | 0.67 | 3.1677 |
| E6 | A | 0.6827 | AA | 95.7118 | 4.4644 | 0.63 | 2.6808 |
| E7 | A | 0.6264 | AAA | 100.0000 | 4.4644 | 0.69 | 3.0925 |
| E8 | A | 0.6852 | AA | 95.6657 | 4.4644 | 0.62 | 2.6672 |
| E9 | A | 0.7069 | A | 84.6901 | 4.4644 | 0.60 | 2.2702 |
| E10 | B | 0.6125 | AAA | 100.0000 | 4.9412 | 0.71 | 3.5049 |
| ⋮ | ⋮ | ⋮ | ⋮ | | ⋮ | | |
| E114 | D | 0.9985 | CC | | No available | | |
| E115 | D | 0.9973 | CCC | | No available | | |
| E116 | D | 0.9985 | CC | | No available | | |
| E117 | D | 0.9921 | B | | No available | | |
| E118 | D | 0.9990 | CC | | No available | | |
| E119 | D | 0.9998 | CC | | No available | | |
| E120 | D | 0.9956 | CCC | | No available | | |
| E121 | D | 1.0000 | C | | No available | | |
| E122 | D | 0.9990 | CC | | No available | | |
| E123 | D | 0.9984 | CCC | | No available | | |

## 7. Sensitivity analysis

In view of the sensitivity analysis in the model, we select the more uncertain parameter--the total annual credit of the bank, and conduct a local sensitivity analysis to explore the impact of the change of the total annual credit of the bank on the annual interest rate and the expected annual profit, as shown in Fig. 6:

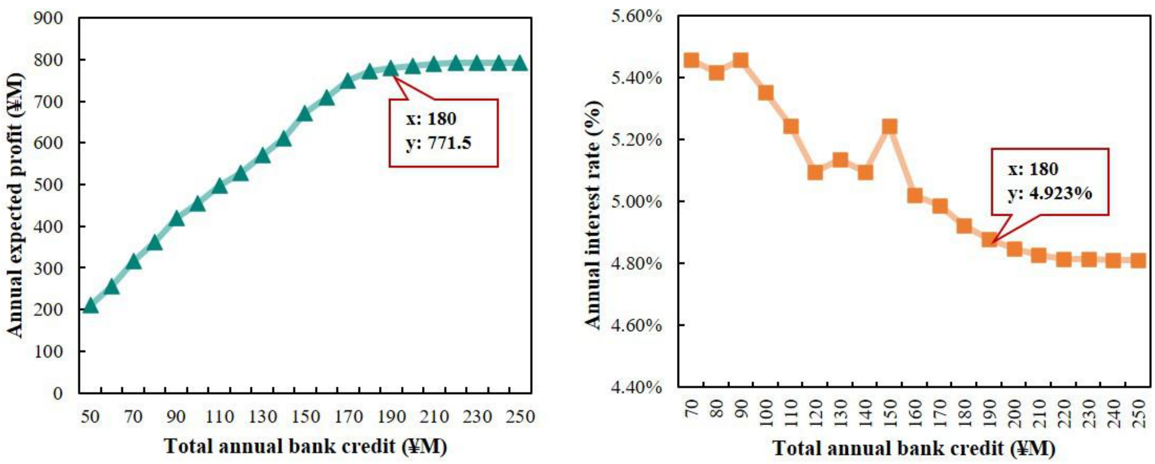


**Fig. 6 The sensitivity relationship between total annual bank credit, bank annual interest rate and expected profit**

As can be seen from Fig. 6, when the bank's annual loan range is [50,250], with the increase of the bank's annual loan line, the annual expected profit shows an upward trend, and the annual interest rate shows a downward trend, but the trend of both changes is getting slower and slower. When the bank's annual loan reaches 1.8 million yuan, the annual expected profit is close to the horizontal line to rise, the upward trend is very slow, the annual interest rate is close to the horizontal line, the downward trend is also very slow.

It shows that when other conditions remain unchanged, such as the range of the loan line, the number of MSMEs, the law between the annual interest rate and the customer turnover rate, the bank is close to the maximum profitability when the total annual credit reaches 1.8 million. If the MSME can have more rapid development, it needs to constantly complete other conditions, such as attracting more MSMEs to borrow money, improving the service system, reducing customer turnover rate, strengthening its comprehensive strength, reforming the system structure, extending the loan quota range, and so on.

## 8. Conclusion

Based on the data of a bank on 123 MSMEs, this paper studied the quantitative credit risk analysis and decision-making of bank to MSMEs. By using the method of theoretical analysis and feature engineering to extract and process information, this paper created a multi-level index system and established an entropy weight-TOPSIS model, solved the credit risk index of each MSME. We divided the credit risk grades and built the credit strategy optimization model, and used the DE algorithm to solve the credit strategy plan of the bank to each MSME. Combined with the relationship between the total annual credit, interest rate and expected profit of the bank, this paper also made a partcial sensitivity analysis of the model, explored the maximum profitability of the bank, and then finally gave helpful suggestions based on the results.

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