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Dalian High-Tech SMEs Growth Evaluation Based on Catastrophe and Principal Component Projection Method

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ABSTRACT

In the course of rapid economic development, high-tech small and medium enterprises (SMEs) are gradually playing an important role, which become important support to regional economic growth and science and technology development. So SMEs growth becomes a universal problem. And how to evaluate the SMEs growth becomes an important step, especially to high-tech SMEs growth. In this paper, catastrophe theory and improved principal components projection method are used and a mutation series of high-tech SMEs growth evaluation index system is built. Taking Dalian high-tech SMEs as an example, high-tech SMEs growth is evaluated, which contributes to high-tech SMEs growth forecast and government to formulate policies to support high-tech SMEs development.

Keywords: *Catastrophe Theory, Improved Principal Components projection Method, Enterprises Growth, High-tech Small and Medium Enterprises (SMEs), Principal Component Projection Method*

1. Introduction

In recent years, with the development of high technology, enormous high-tech SMEs are build, but in which fast growth small and medium high-tech enterprises only account for about 5%[1]. Though the number is low, yet they make a large contribution to job enlargement, wealth increase, new start industry promotion, etc. What factor influences the growth of high-tech SMEs？ That becomes a problem concerned by industrialist, governor, policymaker, banker (especially venture investor) and scholar together. About 20 or 30 years ago, many scholars have discussed this problem from different viewpoints. These researches help understand the high-tech SMEs growth process. But now the research achievement can’t be used to design a model, which can preview the growth potential of high-tech SMEs. In addition, like hypotheses and methods used to different national small and medium-sized enterprises, sometimes unlike empirical analysis outcome is got. The internationalization process of high-tech SMEs is often different from that of more mature industries [2].

Although there is no single agreed definition of high-tech SMEs, there are generally characterized by high-tech SMEs with advanced knowledge and capabilities in technology, and educated workforce, and the ability to adapt quickly to fast changing environments. These characteristics facilitate the internationalization of high-tech SMEs, which have been known to act quickly when windows of opportunity in foreign markets present themselves [3–7].

In China there are many vibrant SMEs, especially the representation of high-tech SMEs, whose survival are the basic form of expression in the contemporary conditions of socialization of production and specialization, and is an important part of the modern collaboration division of labor system. They have become the most active elements to China's economy, which contribute much to China's economic development, technology innovation, and so on.

For the strength, stability and development of the anti-risk capability, the current situation on the high-tech SMEs growth is worrisome. High-tech SMEs growth is fraught with difficulties and hardships, which make the growth become a universal problem [8]. How to evaluate the high-tech SMEs growth is very important. At present, domestic and foreign scholars focus on high-tech SMEs growth study from two aspects [9–10]. That is, how to establish indicators and which methods are used to evaluate. In this paper, catastrophe theory and improved principal components projection method are used and a mutation series of high-tech SMEs growth evaluation index system is built. Taking Dalian high-tech SMEs as an example, high-tech SMEs growth is evaluated, which contributes to their growth forecast and government to formulate policies to support SMEs developments.

2. High-Tech SMEs Evaluation Based on Combination of Catastrophe Theory and Principal Component Projection Method

2.1 High-Tech SMEs Evaluation Based on Catastrophe Theory

Catastrophe theory is a mutation research (qualitative) founded by French mathematician Majorelle Thom, which is about the characteristics of system variables to control the variables following the mathematical theory and taken as ‘a revolution after mathematical calculus [11]. Catastrophe theory is actually a multi-dimensional fuzzy membership function.

To evaluate the complexity and abstract goals, the systematic goals of multi-level contradictions are decomposed. And combining of fuzzy math with the Catastrophe theory, the fuzzy membership function mutation is got.

Using normalization formula to a comprehensive quantitative computing, the final as a parameter is got [12]. The main advantage of the method is not used for indicators of weight. However, it is considered the relative importance of various evaluation indicators, and qualitative integrates and quantitative analysis, which reduce the subjectivity and yet scientific, and is a reasonable, simple and accurate calculation. So Catastrophe theory is a worthwhile evaluation method. To a dynamic system, the influence function of Catastrophe system is $f(x)$. According to Catastrophe theory, all of its critical point congregates into balance-surface. Through the equation to get the first derivative zero That is, $f'(x)=0$, and the singular point can be got through solving $f(x)$ the second derivative, and got $f''(x)=0$. $f'(x)=0$ and $f''(x)=0$ eliminate *x*, the differences point set equation of Catastrophe can be got. Differences point set equation shows that when all control variables meet this equation, the system will mutate. Through the differences point set equation that in decomposition form, a formula can be got. By a formula, hanging different variables with different states are quality into the same state quality.

At present, the total Catastrophe system types is seven, the most common are three. That is, cusp catastrophe system, dovetail catastrophe system and butterfly catastrophe system

The model of cusp catastrophe system is:

$$f(x) = x^4 + ax^2 + bx$$

The model of dovetail catastrophe system is:

$$f(x) = \frac{1}{5}x^5 + \frac{1}{3}ax^3 + \frac{1}{2}bx^2 + cx$$

The model of butterfly catastrophe system is:

$$f(x) = \frac{1}{6}x^6 + \frac{1}{4}ax^4 + \frac{1}{3}bx^3 + \frac{1}{2}cx^2 + dx$$

$f(x)$ means a influence function of a state variable x in a system. And the coefficient of x is *a, b, c, d,* which represents the control variables of the state variables. If an indicator only is decomposed into two sub-indexes, the system can be seen cusp catastrophe system. If an indicator is decomposed into three sub-indexes, the system can be seen as dovetail catastrophe system. And if an indicator is only decomposed into four sub-indexes, the system can be seen butterfly catastrophe system [13].

According to catastrophe theory, in a cusp catastrophe system, the differences point set equation of $f'(x)=0$ and $f''(x)=0$ can be got $\{a=-6x^2,\ b=8x^3\}$. Then the catastrophe fuzzy membership function formula can be gotten.

$$x_a = a^{\frac{1}{2}},\ x_b = b^{\frac{1}{3}}.$$

In the formula, x_a means *x* corresponding to *a*, x_b means *x* corresponding to *b*. Similarly, the formula of dovetail catastrophe system is:

$$x_a = a^{\frac{1}{2}},\ x_b = b^{\frac{1}{3}},\ x_c = c^{\frac{1}{4}}$$

The butterfly catastrophe system is:

$$x_a = a^{\frac{1}{2}},\ x_b = b^{\frac{1}{3}},\ x_c = c^{\frac{1}{4}},\ x_d = d^{\frac{1}{5}}$$

In essence, it is a multi-dimensional fuzzy membership function, any state variables and control variables are within the scope of 0-1. If the raw data is not the number of 0-1, according to the principle ‘add, subtraction, multiplication and division’ the decision-making results unchanged.

2.1.1 The Establishment of the Hierarchical Structure Mode

Firstly, according to the purpose of evaluation, the evaluation purposes are decomposed into multi-level sub-primary and secondary indicators. It just needs to know the bottom original data, and the high-tech SMEs evaluation data can be got.

It not only analyzes the business growth impacting indicators and the classification indicators, but also needs

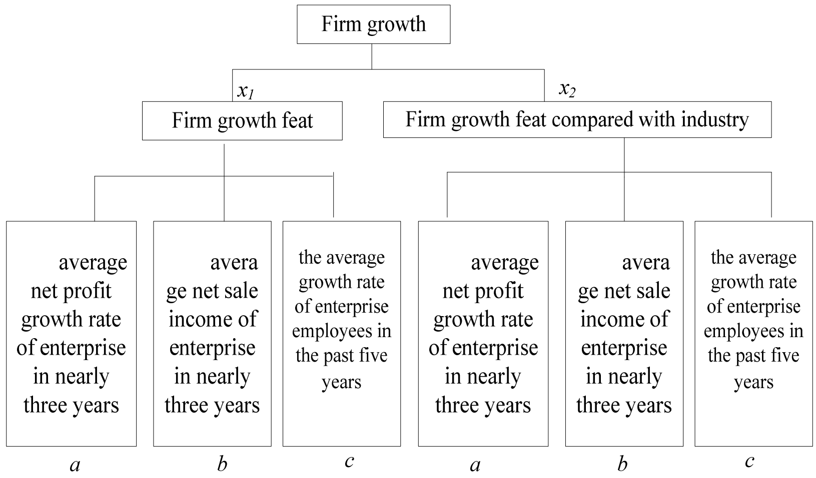

Figure 1. Hierarchical structure model of SMEs growth

to establish evaluation index system according to Catastrophe theory. In this paper, the index system is shown in Figure 1.

2.1.2 Confirming the Catastrophe Type of Hierarchical Structure Model of SMEs Growth

According to Catastrophe theory, the second-level indicators for the type of Catastrophe system is complementary dovetail catastrophe system and the control variables are a, b, c. High-tech SMEs growth feat compared with industry is complementary dovetail catastrophe system and the control variables are a, b, c. The first level high-tech SMEs growth is complementary cusp catastrophe system and the control variables are x_1, x_2.

2.1.3 Calculating the Catastrophe Data and Evaluation

Calculate the bottom control variables of each evaluation units, according to Catastrophe theory, control variables must be taken from the number of 0-1. Therefore, using the following formula:

$$y_{ij} = \frac{p_{ij} - \min\limits_{1\le j\le n} p_{ij}}{\max\limits_{1\le j\le n} p_{ij} - \min\limits_{1\le j\le n} p_{ij}} \quad (1 \le i \le n)$$

In the formula, y_{ij} is the j_{th} control variable number of the i_{th} objective evaluation system, p_{ij} is the j_{th} index number of the i_{th} objective evaluation system, *n is* the number of evaluation units, *m* is the target system for a number of indicators. Subsystem catastrophe number is taken, which can be evaluated for the control variable evaluation of upper system.

2.2 High-Tech SMEs Evaluation Based on Improved Principal Components Projection Method

Unlike traditional principal components projection method, the structure constructed by the improvement of the principal component projection is composed of two parts: a regional assessment and an evaluation criteria object. The steps of calculation are as follows:

2.2.1 Determine the Evaluation Matrix

According to constructing the methods of the evaluated regions, we can determine evaluation matrix. If there are n evaluated objects, every object is described by m indexes, the matrix will be got. It is:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \cdots & \cdots & \cdots \\ x_{n1} & \cdots & x_{nm} \end{pmatrix}$$

In this case, we choose b1 as the average sales growth rate of enterprise in recent three years, b2 as the average employees growth rate of enterprise in recent five years, b3 as the average net profit growth rate of enterprise, and we choose b4, b5, b6 to represents situation of b1, b2, b3 compared to the average level of the same industry respectively, so the total index number is six, that is *m*=6.

2.2.2 Standardizing the Data

For a decision problem with many indexes, given decision matrix, because of different dimensions, the amount scales among indexes will be too different to be compared, and in order to make comprehensive evaluation before using the improved principal component projection, we should eliminate the two kinds of differences above, that is to say, standardizing the matrix X.

Then, standardized evaluation matrix $Y = (y_{ij})_{n\times m}$ will be got $y_{ij} \in [0,1]$. To all values of the standardized indexes, the greater the index is, the better it is. As there are different styles of evaluation indexes, different methods are chosen to deal with. The following method is used to normalize the values of indexes regarding evaluation matrix.

$$y_{ij} = \frac{x_{ij} - \min\limits_{1\le j\le n} x_{ij}}{\max\limits_{1\le j\le n} x_{ij} - \min\limits_{1\le j\le n} x_{ij}} \quad (1 \le i \le n)$$

2.2.3 Determine the Index Weight and Building up Empower-Decided Matrix

There are many methods to determine the index weight, such as subjective method, objective method, empower combination method. In this section, the method of level analysis will be chosen to determine the index weight ω_{ij}, then, weighting the standardized matrix according to weight determined, and ordering that level vectors of empower-decision matrix

$$Z\left\{Z = (z_{ij})_{n\times m},\ z_{ij} = \omega_{ij} \times x_{ij}\right\}$$

Correspond to the evaluated objects, vertical vectors correspond to the indexes are empowered.

The steps on confirming weight with improved principal component projection method: Firstly, building up the hierarchical structure in terms of the characteristics of evaluation indexes. As the table 1 described, indexes of upper levels corresponding to b1, b2 and b3 are represented by B1, indexes of upper levels corresponding to b4, b5 and b6 are represented by B2. Then, comparison and judge matrix are built up, which are used to judge one to one. After the establishment of the target level-structure, the relations of indexes between up and down will be determined. As indexes are in the same level, comparison between one and one according to 9 scales are made (Table 1).

We will get judge-matrix A= $\{a_{ij}\}$.

The values in A should meet the following conditions:

$$a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}}, a_{ii} = 1 \cdot$$

Table 1. The meaning of 9 scales

Number	The importance of grades	a_{ij}
1	*i*, *j* are equally important	1
2	*i* is slightly important	3
3	*i* is obviously important	5
4	*i* is strongly important	7
5	*i* is extremely important	9
6	*i* is slightly less important	1/3
7	*i* is obviously less important	1/5
8	*i* is strongly less important	1/7
9	*i* is extremely less important	1/9

The results are as follows:

$$A_{B_1,B_2} = \begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}$$

$$A_{b_1,b_2,b_3} = A_{b_4,b_5,b_6} = \begin{pmatrix} 1 & 2 & 1/2 \\ 1/2 & 1 & 1/3 \\ 2 & 3 & 1 \end{pmatrix}$$

Finally, the weight is determined.

$$\omega_i = \frac{M_i}{\sum\limits_{i=1}^{n} M_i}$$

In this equation, $M_i = \sqrt[n]{\prod\limits_{j=1}^{n} a_{ij}}$.

The results are as follows:

$$W_{B_1,B_2} = (\omega_{B_1}, \omega_{B_2}) = (0.667, 0.333)\ ;$$

$$W_{b_1,b_2,b_3} = W_{b_4,b_5,b_6} = (\omega_{b_1}, \omega_{b_2}, \omega_{b_3}) = (\omega_{b_4}, \omega_{b_5}, \omega_{b_6}) = (0.315, 0.236, 0.449)$$

$$W_{b_1,b_2,b_3,b_4,b_5,b_6} = (\omega_{B_1}\omega_{b_1}, \omega_{B_1}\omega_{b_2}, \omega_{B_1}\omega_{b_{13}}, \omega_{B_2}\omega_{b_4}, \omega_{B_2}\omega_{b_5}, \omega_{B_2}\omega_{b_6}) = (0.210, 0.157, 0.299, 0.106, 0.079, 0.149)$$

Judging the consistency ratio of the matrix, CR= $\frac{CI}{RI} = \frac{0.0045}{0.52}$ <0.1, which meets the requirements of consistency, and we will find that the largest characteristic value.

$\lambda_{\max}$ =3.009

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{3.009 - 3}{3 - 1} = 0.0045.$$

2.2.4 Orthogonal Transformation of Indexes

Due to the large number of evaluation indexes, interrelated relationship among them will result in overlap evaluation information, and it will interfere with the determination of relatively important positions about indexes. But if the values of the indexes are handled by means of orthogonal transformation, the overlap information among indexes will be filtered. Supposing that W=Z'Z, we could calculate the result with Matlab, then, characteristic values of matrix W will be got.

$$\lambda_1 \ge \lambda_2 \ge \ldots \ge \lambda_n .$$

Corresponding to unit characteristic, vectors are $a_1, a_2, \ldots, a_n$, named A= ($a_1, a_2, \ldots, a_n$). If we order that U=ZA, orthogonal decision-making matrix U= $(u_{ij})_{n\times m}$ can be got, decision-making vector is U= ($u_1, u_2, \ldots, u_n$).

2.2.5 Constructing an Ideal Decision-Making Object and Calculating the Values about Projection

Treating each decision-making object as a dimensional vector and constructing an ideal decision-making object

$$d^* = (d_1, d_2, ..., d_m)$$

Then uniting d^* with $d_j = \max_{1 \le i \le n}(u_{ij})$, we could get the result as follows:

$$d_0^* = \frac{d^*}{\|d^*\|} = \frac{d^*}{\sqrt{d_1^2 + d_2^2 + \ldots + d_m^2}}$$

d_0^* represents the ideal decision-making object, calculating projection values of every evaluated vector about ideal decision-making object:

$$D_i = \bar{u}_i \times d_0^* = \frac{\sum_{j=1}^{m} d_j u_{ij}}{\sqrt{d_1^2 + d_2^2 + \ldots + d_m^2}}$$

2.2.6 Ordering the Projection Values and Determining the Level

By the magnitude of projection values calculated with the equation above, we can judge the closing degree between every evaluated object and ideal object, projection values $0 \le D_i \le 1$, and to D_i, the greater, the better. The greater value represents that the evaluated object $\bar{u}_i$ is better.

If we choose D_i as comprehensive evaluation values of the n evaluated objects, according to the greater-better principle, the final results of evaluation order could be got.

The lastly new k objects also have k projection results, it is that the values of the endpoints about evaluation criteria intervals also have projection values, these k values form k-1 intervals, every interval corresponds to one kind of evaluation criteria level. And n-k projection values of evaluated objects must fall into these k-1 intervals, that is to say, projection values of evaluated objects fall on projection values intervals of endpoints about evaluation criteria intervals. Eventually, the interval fell on indicates that evaluated objects are in the corresponding situation.

2.3 Growth Evaluation of High-Tech SMEs Based on Combination

There are many methods to evaluate the growth of the enterprise, such as Catastrophe Theory, Principal Component Projection Method. If we combine the evaluate results of two methods just mentioned to play their own strengths, it is clear that the effect of the evaluation will be improved. And we combine the two kinds of results to make the weighted evaluation. The basic processes are as follows.

Firstly, using …to deal with the two kinds of results, secondly, using the formula $y = \beta y_1 + (1-\beta) y_2$ to get the results of combined evaluation, in the formula: y_1 represents evaluation results which are dealt with Catastrophe Theory after normalization, y_2 represents evaluation results which are dealt with Principal Component Projection Method after normalization, β represents the weighted factor. Due to a number of expert advisory, and the specific circumstances of data collection, we select 0.5 as the reasonable value of β.

3. Empirical Analysis on Dalian High-Tech SMEs Growth Evaluation

3.1 Source of the Data and Description of the Data Structure

All data of this study result from surveying enterprises. The region where questionnaires are released is Dalian, the person in charge of the business or senior managers knowing about the enterprise very well are chose to fill in the questionnaires. The number of the questionnaires released is 167, among them, 112 recovered are valid, recovery rate is 67.1%. The enterprises selected in this time meet the needs of the research basically.

By analyzing the data of 112 valid sample, we get the Ownership situation: Collective enterprises account for 2.66%, private enterprises account for 50.67%, stock companies limited account for 5.33%, limited liability companies account for 21.33%, joint-stock cooperative enterprises account for 1.33%, foreign-funded enterprises account for 5.33%, equity joint venture companies account for 10.67%, others account for 2.67%.

Situation of the business type: Production-oriented enterprises account for 24%. Trade Enterprises account for 20%; Consulting, service-oriented enterprises account for 29.33%. Financial investment companies account for 1.33%. Outsourcing service accounts for 5.33%. Other types account for 14.67%; others account for 5.33%.

3.2 The Effectiveness and Reliability of High-Tech SMEs Growth Evaluation

Before data analysis, to test the effectiveness and reliability of data, data reliability test is needed. Cronbath α is a major test of the inherent reliability, through which the α of six grow feat is got, that is 0.910. That means the results of the questionnaire have high internal consistency coefficient. And the performance of the overall business growth correlation coefficient shows in Table 2.

Before a large sample investigation, 20 high-tech SMEs are randomly selected to be interviewed and pre-investigated in Dalian high-tech park. Table 3 lists the evaluation results of 20 SMEs based on Catastrophe the-

Table 2. Overall high-tech SMEs growth performance coefficient

Number	Content	Overall SMEs growth performance coefficient
Y 1	Average net profit growth rate of enterprise in nearly three years	.725
Y 2	Average net sale income of enterprise in nearly three years	.713
Y 3	The average growth rate of enterprise employees in the past five years	.781
Y 4	Average net profit growth rate of enterprise compared with other firm in a industry in nearly three years	.786
Y 5	Average net sale income of enterprise compared with other firm in a industry in nearly three years	.727
Y 6	The average growth rate of enterprise employees compared with other firm in a industry in the past five years	.773

ory and principle component projection method. According to the 112 SMEs research results, the statistics on high-tech SMEs growth are got in Table 4.

High-tech SMEs growth is a process that make enterprises resource value-added. To individual enterprise, it always grows up with the scale expansion and corresponding complexity increase companions. According to the evaluation findings of SMEs growth, we take that the enterprises score between 0.6-1.0 the enterprises as the fast-growing enterprises score between 0.0-0.4. The enterprises are as the low-growing enterprises.

Evaluating on the high-tech SMEs growth based on catastrophe theory and principle component projection method, in addition to provide a new tool for the effective analysis and comprehensive evaluation of high-tech SMEs, but also have the following practical value:

The government can judge the overall development situation according to the evaluation results, which contributes to develop targeted strategies, policies and measures to promote high-tech SMEs development.

High-tech SMEs can have a comprehensive understanding of the overall development of other High-tech SMEs, which help to judge enterprises in the industry performance level. Analyzing on the firm growth and potential sources can help to strengthen the growth of enterprise management clearly in the specific direction.

Table 3. The growth evaluation of high-tech SMEs

Firm Number	Catastrophe theory		Principle component projection method		Combination
	Before Normalization	After Normalization	Before Normalization	After Normalization	
1	0.794	0.835	0.206	0.587	0.711
2	0.773	0.813	0.204	0.581	0.697
3	0.390	0.410	0.077	0.219	0.315
4	0.951	1.000	0.351	1.000	1.000
6	0.624	0.656	0.171	0.487	0.572
7	0.390	0.410	0.077	0.219	0.315
8	0.856	0.900	0.249	0.709	0.805
9	0.411	0.432	0.050	0.142	0.287
10	0.913	0.960	0.308	0.877	0.919
11	0.781	0.821	0.195	0.556	0.688
12	0.446	0.469	0.060	0.171	0.320
13	0.841	0.884	0.233	0.664	0.774
14	0.902	0.948	0.292	0.832	0.890
15	0.841	0.884	0.233	0.664	0.774
16	0.841	0.884	0.233	0.664	0.774
17	0.841	0.884	0.233	0.664	0.774
18	0.781	0.821	0.195	0.556	0.688
19	0.781	0.821	0.195	0.556	0.688
20	0.841	0.884	0.233	0.664	0.774
21	0.438	0.461	0.058	0.165	0.313

Table 4. Study on the evaluation results of SMEs growth

Growth evaluation	0.0-0.4	0.4-0.6	0.6-1.0	Total
Sample Quantity	55	28	29	112
Sample percent	50.8%	23.5%	25.7%	100%

The evaluation results contribute to social research institutions for more in-depth analysis of empirical and theoretical research. Study on the high-tech SMEs development is still in the initial stage. All the available research data, information is also scarce. Evaluation on high-tech SMEs growth can provide a lot of empirical analysis and data support, which help to deepen the high-tech SMEs research.

4. Conclusions

In China there are many vibrant SMEs, especially the representative of high-tech SMEs, whose survival are the basic form of expression in the contemporary conditions of socialization of production and specialization, and is an important part of the modern collaboration division of labor system. Catastrophe theory is used and a mutation series of high-tech SMEs growth evaluation index system is built. Evidence shows the growth of Dalian high-tech SMEs is relatively slow, nearly 50% of Dalian high-tech SMEs grows slowly, which need to be regarded by the government and Dalian high-tech SMEs. Some countermeasures should be put forward by the industry or the government to support the fast growth of Dalian high-tech SMEs.

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