International Journal of u- and e- Service, Science and Technology
Vol.9, No. 5 (2016), pp.429-440
http://dx.doi.org/10.14257/ijunesst.2016.9.5.39

An Improved Method of Grey Clustering Based on Entropy for the Evaluation of Enterprise's Innovation Capabilities

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Abstract

Based on Fujian industrial enterprises' technological innovation survey, this established evaluation index system of enterprise's innovation capabilities. Then, it presented an improved grey clustering model with entropy, and used the model to systematically evaluate the innovation capabilities of enterprises. Empirical study of Fujian enterprises' innovation capabilities evaluation showed that the improved grey clustering method had a trait of simple, objective, easy to operating, easy to using and so on, and it was practical for assessment enterprises's innovation capabilities in little information, small sample condition.

Keywords: *Improved Grey Clustering Model, Entropy, Evaluation of Enterprise's Innovation Capabilities*

1. Introduction

Innovation ability is the lasting impetus which an enterprise maintain its competitive advantage and sustainable development. Scientific evaluation of enterprises' innovation capabilities helps enterprises to understand their potential and shortcomings in the implementation of innovation activities. Thereby they could learn from others' strong points and close the gap, and take targeted measures to enhance the innovation ability.

2. Establishment of the Assessment Indicator System for Enterprises' Innovation Capabilities

Innovation capability is a system ability of an enterprise, it embodied in the entire process from new technology research and development, production and commercialization (Çakar, Nigar and Alper, 2010) [1]. Leonard-Barton (1998) believed that innovation capability of the enterprise consisted of technician, the skills of senior personnel, technology system capacity, managing system capacity and the corporate values [2]. Szeto (2000) noted that the innovation ability was the overall capacity of enterprise causing innovation to develop new products to meet market needs[3]. Lawson and Danny (2007) thought that innovation ability consisted of the innovation resource input, innovation managing ability, innovation orientation, R&D ability, manufacturing capacity, marketing abilities as well as their combined efficiency-innovation output ability[4]. In sum, enterprises' innovation capabilities are a synthesis of multiple abilities, which take technology research and development as the core, and innovation output as the target.

Design of index system for the evaluation of enterprise's innovation capabilities must follow the principles of scientific, systematic, comparable, operational, as well as practicability. The composition of its indexes should do fewer but better, which

ISSN: 2005-4246 IJUNESST

should get to the point, and also reflect the real situation. Therefore, this paper based on survey data of technical innovation of industrial enterprises in Fujian province, combined with the opinion of the scholars mentioned above, sets up multi-level evaluation index system of enterprise's technology innovation ability from 5 aspects as follows: ability of innovating technology, input ability of innovation elements, output ability of innovation elements, management ability of innovation elements, and marketing ability of innovation elements, as shown in Table1. Quantitative indicators data in Table 1 are acquired from enterprise statistical data, and qualitative data comes out from all experts involving in the investigation to score and average.

Table 1. Evaluation Index System of Enterprises' Innovation Ability

Target layer	Criterion layer	Index layer
Enterprises' innovation Capability, (X)	Ability of innovating technology, (X_1)	Overall technical level of enterprises in the industry's position, (X_{11})
		The level of R&D institutions, (X_{12})
		R&D staff accounting for the proportion of the total number of employees, (X_{13})
	Input ability of innovation Elements, (X_2)	R&D input accounting for revenue, (X_{21})
		Digestion and absorption of funds accounting for revenue, (X_{22})
		Technical training accounting for revenue, (X_{23})
	Output ability of innovation elements, (X_3)	Thousands of scientists and engineers with the patent number, (X_{31})
		Numbers of participation in international, national and industry standards, (X_{32})
		New products (services) income accounting for all sales revenue, (X_{33})
		Per capita sales net profit in enterprise, (X_{34})
	Management ability of innovation elements, (X_4)	Innovation development strategy, (X_{41})
		The improvement of intellectual property management systems, (X_{42})
		Innovation motivation mechanism, (X_{43})
		Enterprise informationization level, (X_{44})
	Marketing ability of innovation elements, (X_5)	Technology transfer, license funding accounting for revenue, (X_{51})
		Numbers of enterprise getting famous, provincial famous trademark, (X_{52})
		Numbers of enterprise getting national, provincial famous brand product, (X_{53})

3. Principle and Implementation Steps of Improved Grey Clustering Assessment Based on Entropy Technology

3.1. Method Principle

Grey clustering assessment was proposed in 1993 by Professor Sifeng Liu [5], which is a multilevel evaluation and decision method of uncertainty problem. Evaluating principle of the method is utilizing grey system theory to deal with the information of the evaluated objective, and convert it into whitening function which can be used to describe the grey class belonging to the objective. Through the function, it can calculate whitening clustering coefficient of the objective in each evaluation index. On this basis, it accounts the hierarchical comprehensive evaluation index system based on clustering coefficient. Then it evaluates comprehensively according to the results [5-6].

The concept of entropy was originally a concept of thermodynamics; it was first introduced into Information Theory in 1948 by Shannon [7]. In information theory, entropy is the important metrics of the disorder degree of system, it means how much can be extracted from a set of uncertain information. In General, in the actual evaluation or in the decision-making process, the position of various indicators is

different, passing of information is also not the same. If object in an index value is more different (the variation degree is greater), then the entropy value is smaller, which means the indicator provides more effective information and plays a greater role in synthesized evaluation. That is the weights should be greater, while the smaller. Therefore, according to the variation degree of the index value, use entropy can objectively estimate the degree of contribution of the index to the evaluation target, that is index weight [8].

Although entropy method can accurately reflect the utility value of the indicators information entropy values, it lacks lateral comparison between various indicators, and it need complete survey data, so it is limited in application. While the grey clustering can compensate for defects of the entropy value evaluation, whose mainly comprehensive evaluate the pros and cons of strategies according to the horizontal multiple indexes, it is suitable for the "poor information", "few sample" of multi-objective decision making evaluation.

However, traditional Grey Clustering generally uses the Delphi method or AHP level judgement method of determining the index weight, it ignored the "sample information" and not economical complexity and subjectivity and bias and other defects in actual implementation. Therefore, this paper puts forward an improved Grey Clustering assessment based on Entropy Method, and uses it in the evaluation of enterprises' innovation capabilities. The improved grey clustering method uses information entropy technology to extract the sample information to determine the weight of the evaluation index, then combine with grey clustering function to systematicly evaluate enterprise's innovation capabilities. Its basic principle and implementation steps are as follows.

3.2. Implementation Step

Suppose it has n enterprises, m evaluation indexes, s different classes of grey, and the enterprise i of sample observations on indicator j is x_{ij}. Then use the improved Grey Clustering assessment based on Entropy method to evaluate the innovation capabilities of enterprise i according to the value of x_{ij}. The basic steps are as follows.

3.2.1. Measure the Weight of Each Indicator with Entropy Method: (1) According to the polarity of each indicator, standardize all index data of enterprises' innovation capabilities. For the positive indicator data, use formula (1) to standardize; and for the negative index data, use formula (2) to standardize.

$$X'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \qquad \text{formula (1)}$$

$$X'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \qquad \text{formula (2)}$$

(2) Calculate the index information entropy by the formula (3)

$$h_j = -k \sum_{i=1}^{m} \{(X'_{ij} \Big/ \sum_{i=1}^{m} X'_{ij}) * \ln(X'_{ij} \Big/ \sum_{i=1}^{m} X'_{ij})\} \qquad \text{formula (3)}$$

In formula (3), $k = \ln m$; and the index information entropy h_j =0, if the value of index data standardization X'_{ij} =0.

(3) Calculate the redundancy of each index's information entropy by the formula (4)

$$d_j = 1 - h_j \qquad \text{formula (4)}$$

(4) Use the redundancy of information entropy to calculate the index weight through the formula (5)

$$\eta_j = d_j \Big/ \sum_{j=1}^{n} d_j \qquad \text{formula (5)}$$

3.2.2. Grey Clustering Evaluation: (1) Evaluation of grey category: Each index is divided into s grey categories according to its range, such as the range $[a_1, a_{s+1}]$ of indicators j were divided into $[a_1, a_2], \cdots, [a_{k-1}, a_k], \cdots, [a_{s-1}, a_s], [a_s, a_{s+1}]$; meanwhile, set the grey class corresponding to one of these comment classes; the higher the grey class, the higher the comment class. Then get the assessment set vector $\mu = (1, 2, \cdots, s)$, which stand for comment class vectors.

(2) Domain extension of evaluation index and calculation of its whiten clustering coefficient

Extend each evaluation index's domain according to the treating method of reference [9], and build whitening function using the formula (6), then calculate each index whiten clustering coefficient with the formula (7).

$$\lambda_k = (a_k + a_{k+1}) / 2 \qquad \text{formula (6)}$$

$$f_j^k(x) = \begin{cases} \dfrac{x - a_{k-1}}{\lambda_k - a_{k-1}}, & x \in [a_{k-1}, \lambda_k] \\ \dfrac{a_{k+2} - x}{a_{k+2} - \lambda_k}, & x \in [\lambda_k, a_{k+2}] \\ 0, & x \notin [a_{k-1}, a_{k+2}] \end{cases} \qquad \text{formula (7)}$$

(3) Calculation of the integrated clustering coefficient

Calculate all the integrated clustering coefficients σ_k^i of the criterion layer and target layer through the formula (8).

$$\sigma_k^i = \sum_{j=1}^{m} f_j^k(x_{ij}) * \eta_j \qquad \text{formula (8)}$$

(4) Assess comprehensively the value and evaluate the order of innovation ability

Calculate the comprehensive evaluation values s^i of the criterion layer and target layer through formula (9), and evaluate the order of enterprise's innovation capability by the value of s^i.

$$S^i = \sum_{k=1}^{n} (\sigma_k^i / \sum_{j=1}^{n} \sigma_j^i) * \mu_k \qquad \text{formula (9)}$$

4. Empirical Research on the Improved Grey Clustering Assessment of Enterprises' Innovation Ability-- Case Study of Enterprises in Fujian, China

There are four companies in Fujian province—Fujian E1 Batteries Liability Company, Fuzhou E2 Technology Liability Company, Fujian E3 Communication Technology Liability Company, and E4 Optoelectronics Co., Ltd (represented by E1, E2, E3 and E4 respectively). Collect and obtained original data of the enterprises' technology innovation by survey. Take index layer of Table 1 as sequence, arrange the index data vector of the four companies are as follows:

E1=(8,6,0.104,0.052,0.258,0.004,352.944,461.756,0.512,28.814,4,2,3,4,0.17,2,6);
E2=(10,10,0.63,0.397,0.173,0.08,749.72,511.049,0.454,39.881,3,4,2,3,0.114,1,3);
E3=(7,5,0.696,0.464,0.235,0.096,464.281,334.2,0.802,14.498,3,3,4,5,0.251,1,4);
E4=(9,8,0.648,0.435,0.261,0.093,695.876,573.635,0.687,42.075,5,4,5,4,0.239,3,5);

Then, evaluate their innovation capabilities with the improved Grey Clustering assessment mentioned above.

4.1. Calculation of the Index Weight by Entropy Method

(1) Standardize all index data, as is shown in Table 2.

Table 2. Standardization of All Index Data

Enterprise	x'_{11}	x'_{12}	x'_{13}	x'_{21}	x'_{22}	x'_{23}	x'_{31}	x'_{32}	x'_{33}	x'_{34}
E1	0.333	0.2	0	0	0.966	0	0	0.533	0.167	0.519
E2	1	1	0.889	0.837	0	0.826	1	0.739	0	0.92
E3	0	0	1	1	0.705	1	0.281	0	1	0
E4	0.667	0.6	0.919	0.93	1	0.967	0.864	1	0.67	1
Enterprise	x'_{41}	x'_{42}	x'_{43}	x'_{44}	x'_{51}	x'_{52}	x'_{53}			
E1	0.5	0	0.333	0.5	0.409	0.5	1			
E2	0	1	0	0	0	0	0			
E3	0	0.5	0.667	1	1	0	0.333			
E4	1	1	1	0.5	0.912	1	0.667			

(2) Use entropy method to calculate weight of innovation ability evaluation index, as is shown in Table 3.

Table 3. Entropy and Weight of Evaluation Index

Criterion	Index	Entropy h_j	Redundancy d_j	Levels weight η_j	Combined weight η'_j
X_1	X_{11}	0.729	0.271	0.337	0.055
	X_{12}	0.676	0.324	0.403	0.066
	X_{13}	0.792	0.208	0.260	0.042
X_2	X_{21}	0.791	0.209	0.329	0.043
	X_{22}	0.784	0.216	0.340	0.044
	X_{23}	0.79	0.21	0.331	0.043

X_3	X_{31}	0.713	0.287	0.263	0.059
	X_{32}	0.769	0.231	0.212	0.047
	X_{33}	0.661	0.339	0.311	0.069
	X_{34}	0.767	0.233	0.214	0.048
X_4	X_{41}	0.459	0.541	0.416	0.111
	X_{42}	0.761	0.239	0.184	0.049
	X_{43}	0.729	0.271	0.208	0.055
	X_{44}	0.75	0.25	0.192	0.051
X_5	X_{51}	0.747	0.253	0.238	0.052
	X_{52}	0.459	0.541	0.508	0.111
	X_{53}	0.729	0.271	0.254	0.055

4.2. Divide the Indicator Grey Class and Calculate the Whitening Clustering Coefficient

Firstly, according to the principles of benchmarking and expert surveys, divide the enterprises' innovation capabilities class into 5 grey classes(each index's grey class intervals is shown in Table 4. Grey class number is set as k, k=1,2,3,4,5 respectively representing comment class as "excellent", "good", "medium" , "poor" and "worst"[6]; and specify the assessment set vector $\mu = (1, 2, 3, 4, 5)$, which corresponding to the comments class; then extend each evaluation index's domain, as is shown in Table 4.

Table 4. Grey Class of Evaluation Index and Its Domain Extention

Criterion	Index	Worst	Poor	Medium	Good	Excellent	Index extention value	
		$[a_1,a_2)$	$[a_2,a_3)$	$[a_3,a_4)$	$[a_4,a_5)$	$[a_5,a_6)$	a_0	a_7
X_1	X_{11}	[1,2)	[2,4)	[4,6)	[6,9)	[9,10)	0	11
	X_{12}	[1,2)	[2,4)	[4,6)	[6,9)	[9,10)	0	11
	X_{13}	[0.06,0.108)	[0.108,0.267)	[0.267,0.458)	[0.458,0.617)	[0.617,0.696)	0.01	0.701
X_2	X_{21}	[0.015,0.048)	[0.048,0.159)	[0.159,0.293)	[0.293,0.404)	[0.404,0.46)	0.005	0.47
	X_{22}	[0.005,0.025)	[0.025,0.085)	[0.085,0.185)	[0.185,0.245)	[0.245,0.265)	0.003	0.268
	X_{23}	[0.003,0.008)	[0.008,0.033)	[0.033,0.063)	[0.063,0.088)	[0.088,0.1)	0.001	0.102
X_3	X_{31}	[31.47,62.85)	[62.85,272.35)	[272.35,523.75)	[523.75,733.25)	[733.25,838)	0	880
	X_{32}	[9.531,42.225)	[42.225,182.975)	[182.975,361.875)	[361.875,502.625)	[502.625,575)	0	580
	X_{33}	[0.039,0.094)	[0.094,0.322)	[0.322,0.595)	[0.595,0.823)	[0.823,1)	0.014	1.025
	X_{34}	[0.84,5.268)	[5.268,15.196)	[15.196,28.109)	[28.109,38.037)	[38.037,43)	0.5	45
X_4	X_{41}	[0.5,1.0)	[1.0,2.0)	[2.0,3.5)	[3.5,4.5)	[4.5,5)	0.2	5.3
	X_{42}	[1,1.5)	[1.5,2.5)	[2.5,3.5)	[3.5,4.5)	[4.5,5)	0.5	5.5
	X_{43}	[1,1.5)	[1.5,2.5)	[2.5,3.5)	[3.5,4.5)	[4.5,5)	0.5	5.5
	X_{44}	[0.8,1.3)	[1.3,2.3)	[2.3,3.5)	[3.5,4.5)	[4.5,5)	0.3	5.5
X_5	X_{51}	[0.005,0.035)	[0.035,0.15)	[0.15,0.288)	[0.288,0.403)	[0.403,0.46)	0	0.465
	X_{52}	[0.106,0.225)	[0.225,0.975)	[0.975,1.875)	[1.875,2.625)	[2.625,3)	0	3.1
	X_{53}	[0.3,1.5)	[1.5,3.5)	[3.5,6.5)	[6.5,8.5)	[8.5,9.7)	0	10

Secondly, calculate its whitening clustering coefficient of the corresponding indicators according the raw data of the four enterprises' innovation ability evaluation index data, as shown in Table 5.

Table 5. Evaluation Index of Whitening Clustering Coefficient

Enterprise	Grey class	X_{11}	X_{12}	X_{13}	X_{21}	X_{22}	X_{23}	X_{31}	X_{32}	X_{33}	X_{34}
E1	f^1	0	0	0.891	0.839	0	0.667	0	0	0	0
	f^2	0	0	0.345	0.418	0	0.057	0.48	0	0.214	0
	f^3	0.25	0.75	0	0.022	0	0	0.865	0.178	0.853	0.563
	f^4	0.8	0.571	0	0	0.14	0	0.226	0.793	0.491	0.762
	f^5	0.571	0	0	0	0.769	0	0	0.564	0	0.057
E2	f^1	0	0	0	0	0	0	0	0	0	0
	f^2	0	0	0	0	0.092	0	0	0	0.364	0
	f^3	0	0	0	0.039	0.655	0.2	0	0	0.988	0
	f^4	0	0	0.416	0.565	0.677	0.816	0.421	0.448	0.341	0.314
	f^5	0.667	0.667	0.866	0.748	0	0.548	0.863	0.843	0	0.949
E3	f^1	0	0	0	0	0	0	0	0	0	0.057
	f^2	0	0.333	0	0	0	0	0.167	0.111	0	0.761
	f^3	0.5	1	0	0	0.091	0	0.802	0.732	0.058	0.563
	f^4	0.857	0.286	0	0	0.6	0.163	0.539	0.607	0.68	0
	f^5	0.286	0	0.112	0.158	0.714	0.75	0	0	0.654	0
E4	f^1	0	0	0	0	0	0	0	0	0	0
	f^2	0	0	0	0	0	0	0	0	0	0
	f^3	0	0.25	0	0	0	0	0.111	0	0.373	0
	f^4	0.4	0.8	0.303	0.224	0.08	0.286	0.678	0.01	0.943	0.093
	f^5	0.857	0.571	0.957	0.921	0.538	0.968	0.657	0.155	0.291	0.653
Enterprise	Grey class	X_{41}	X_{42}	X_{43}	X_{44}	X_{51}	X_{52}	X_{53}			
E1	f^1	0	0.4	0	0	0	0	0			
	f^2	0	1	0.333	0	0.604	0	0.125			
	f^3	0.286	0.333	1	0.313	0.734	0.521	0.714			
	f^4	1	0	0.333	1	0.102	0.804	0.625			
	f^5	0.4	0	0	0.4	0	0.133	0			
E2	f^1	0	0	0.4	0	0.277	0	0.192			
	f^2	0.25	0	1	0.294	0.89	0.686	0.875			
	f^3	0.857	0.333	0.333	0.938	0.429	0.646	0.429			
	f^4	0.5	1	0	0.412	0	0.02	0			
	f^5	0	0.4	0	0	0	0	0			
E3	f^1	0	0	0	0	0	0	0			
	f^2	0.25	0.333	0	0	0.189	0.686	0.625			
	f^3	0.857	1	0.333	0	0.826	0.646	0.714			

	f^4	0.5	0.333	1	0	0.517	0.02	0.125			
	f^5	0	0	0.4	0.667	0	0	0			
E4	f^1	0	0	0	0	0	0	0			
	f^2	0	0	0	0	0.251	0	0.375			
	f^3	0	0.333	0	0.313	0.891	0	1			
	f^4	0	1	0	1	0.455	0	0.375			
	f^5	0.545	0.4	0.667	0.4	0	0.348	0			

4.3. Calculate Integrated Clustering Coefficient of the Evaluation Indexes

Calculate the integrated clustering coefficient of criterion layers and target layer respectively according to the formula (8), and get the results are shown in Table 6.

Table 6. The Integrated Clustering Coefficient of Criterion Layers and Target Layer

Code	E1					E2				
	σ_1	σ_2	σ_3	σ_4	σ_5	σ_1	σ_2	σ_3	σ_4	σ_5
X_1	0.232	0.09	0.387	0.5	0.192	0	0	0	0.108	0.719
X_2	0.497	0.156	0.007	0.048	0.261	0	0.031	0.302	0.686	0.427
X_3	0	0.193	0.651	0.543	0.132	0	0.113	0.307	0.379	0.609
X_4	0.074	0.253	0.448	0.677	0.243	0.083	0.368	0.667	0.471	0.174
X_5	0	0.176	0.621	0.591	0.068	0.115	0.783	0.539	0.41	0
X	0.122	0.184	0.464	0.518	0.174	0.047	0.298	0.403	0.406	0.478
Code	E3					E4				
	σ_1	σ_2	σ_3	σ_4	σ_5	σ_1	σ_2	σ_3	σ_4	σ_5
X_1	0	0.134	0.572	0.404	0.126	0	0	0.101	0.536	0.768
X_2	0	0	0.031	0.258	0.543	0	0	0	0.196	0.806
X_3	0.012	0.23	0.505	0.482	0.203	0	0	0.145	0.494	0.436
X_4	0	0.165	0.61	0.477	0.211	0	0	0.121	0.376	0.516
X_5	0	0.552	0.706	0.165	0	0	0.155	0.466	0.204	0.177
X	0.003	0.237	0.526	0.370	0.193	0	0.034	0.183	0.367	0.503

4.4. Calculate the Overall Evaluation Value and Evaluate the Enterprises' Innovation Capabilities

According to the formula (9), calculate the comprehensive evaluation value, as shown in Table 7. Then, rank the four enterprises' technology innovation capabilities by the value of S^i: E2 $\succ$ E4 $\succ$ E3 $\succ$ E1 on ability of innovating technology; E4 $\succ$ E3 $\succ$ E2 $\succ$ E1 on input ability of innovation elements; E4 $\succ$ E2 $\succ$ E3 $\succ$ E1 on output ability of innovation elements; E4 $\succ$ E3 $\succ$ E1 $\succ$ E2 on management ability of innovation elements; E3 $\succ$ E4 $\succ$ E2 $\succ$ E1 on marketing ability of innovation elements; and on overall innovation ability, E4 $\succ$ E2 $\succ$ E3 $\succ$ E1; the ranking results are depicted in Figure 1 and Figure 2. It is indicated by comparison of the four companies, all capabilities of E1 except management ability of innovation elements are relatively weak; in terms of E2, the main capabilities

influencing its technology innovation include management ability and marketing capacity of innovation elements; as to E3, its innovation capabilities were mainly influenced by output ability of innovation elements and ability of innovating technology; for E4, marketing ability of innovation elements were the bottleneck factors hindering its promotion of innovation capability.

Table 7. Comprehensive Evaluation Value of the Four Enterprises' Innovation Capabilities

Enterprises	Ability of innovating technology	Input ability of innovation elements	Output ability of innovation elements	Management ability of innovation elements	Marketing ability of innovation elements	Overall innovation ability
E1	2.101	1.123	2.161	3.28	1.9	2.131
E2	4.869	4.044	4.054	3.162	2.674	3.594
E3	3.422	4.615	2.438	3.502	3.728	3.385
E4	4.475	4.804	4.271	4.390	3.402	4.233

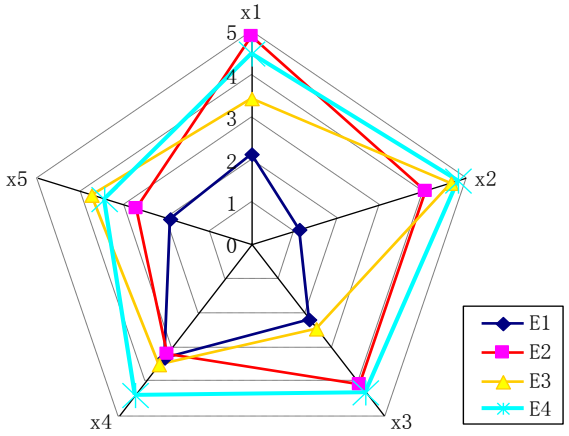

Figure 1. Sub-Capabilities/Criterion-Capabilities of the Four Enterprises' Technology Innovation

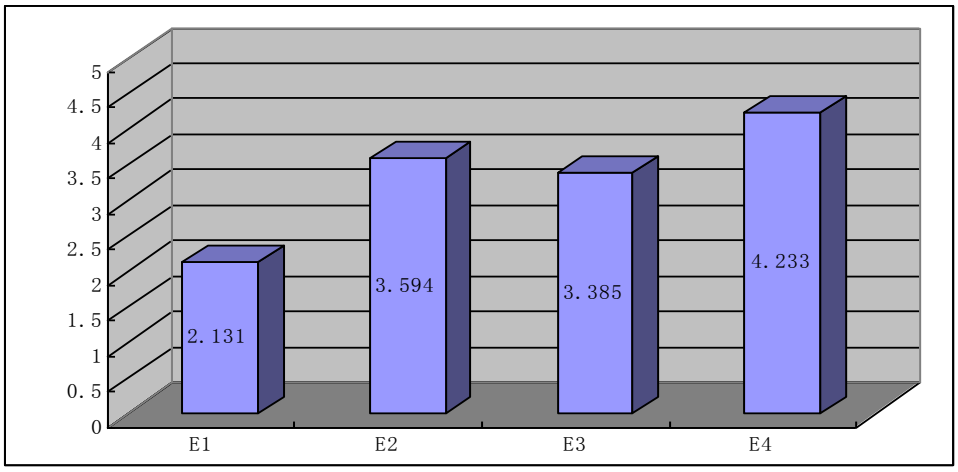

Figure 2. Overall-Capabilities of the Four Enterprises' Technology Innovation

5. Conclusion

The evaluation of enterprise's innovation capabilities is a systematic assessment problem with multi-index, multi-level and multi-object. To solve the problem, this paper presented an improved Grey Cluster method which utilized information entropy technologies to grant weight to evaluation index objectively, and then realized multidimensional comprehensive evaluation by use of Grey Cluster model. The empirical study of Fujian enterprises indicated that it was effective to use the method to systematicly evaluate enterprises' innovation capabilities, and its evaluation result was comparatively objective and accurate.

Acknowledgments

This paper was supported by the National Natural Science Foundation of China (Grant No. 71403052).

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