Competitiveness Evaluation of Manufacturing Industry based on Weighted Grey Correlation

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Abstract

Manufacturing industry is playing an important role in social and economic system,while it is "big but not strong" that is more prominent in developing regions. In order to upgrade manufacturing industry, competitiveness evaluation of manufacturing industry is studied based on weighted grey correlation using analytical hierarchy process and grey correlation analysis.First, statistical data concerned withmanufacturing industry competitiveness are summarized and compared in six developing regions. Then, an evaluation system of manufacturing industrycovering 22 indicators is constructed from economics, scale, R&D and ecology points of view. Furthermore, by using weighted grey correlation which is combined with analytic hierarchy process and grey correlation analysis methods, a simulation approach considering uncertainty on weight and identification coefficient is developed to make a more reliable assessment. Finally, on the basis of the models and approaches, an empirical study on manufacturing industry competitiveness is carried out and simulation results show that this novel approach can provide information and insights for competitiveness evaluation.

Keywords: Competitiveness Evaluation, Weighted Grey Correlation, Simulation Approach, AHP,Manufacturing Industry

I. Introduction

As an important sector in a nation's economic system, manufacturing industry has witnessed a rapid development sinceP.R.C founded in 1949, especially reform and open-up policy execution from 1978 to now. Although great achievements have been made, there still exists quite a few shortcomings and disadvantages which are embodied in weak capability of independent innovation, poor resources utilization efficiency and lower industry structure etc. In a word, manufacturing industry is "big but not strong". Consequently,a long-term planning framework for the future manufacturing development called "Made in China 2025"[1] was issued in 2015. In central China, there are six provinces including Hubei, Hunan, Jiangxi, Anhui, and Shanxi, in which their population accounts for 26.5 percent in China. Also, these six provinces are located in an extremely especial geographical region, connecting all directions from west to east and from south to north. With the strategy called "The Rise of Central China" strategy [2] put forward, it's necessary to evaluate manufacturing competitiveness within central China and to point out their advantages and disadvantages so as to help upgrade manufacturing industry and promote their competitiveness.

During the last decades, a good deal of studies on competitiveness evaluation of manufacturing industry have been made which can be classified two categories. One is concerned with theory framework and evaluation indicator system, while the other is relevant to evaluation approaches and methods. For the theory framework and evaluation indicator system, one of researches which have a widely spread influence was an ICOP evaluation framework [3] established by Wageningen university in the Netherlands in 1989. Later, a universally acknowledged paradigm SCP (Structure-Conduct-Performance) is frequently adopted from industrial economics point of view [4]. Based on these theory frameworks,various indicators [5-10] are constructed such as industry performance (output value, productivity, increasing rate), innovation, and sustainability etc. As for the evaluation methods, the kinds of approaches such as shift-share [11], analytic hierarchy process [12], subdivision comparison [13,14], factor analysis [15] and development envelop analysis [16] areemployed to evaluate manufacturing industry

competitiveness.

In this paper, we focus on manufacturing industry competitiveness of six provinces in central China. The main contributions of this work lie in that not only isan evaluation indicator system put forward based on SCP paradigm, a novel simulation approach combined analytical hierarchy process with grey correlation analysis is used to give a more reliable evidence for the evaluation. The remainder of the paper is organized as follows. Section II summarizes the current situations of manufacturing industry of six provinces in central China from scale, R&D, economic efficiency and ecological aspects. Then, an assessment indicator system is constructed based on SCP paradigm and a simulation approach considering uncertainty of weight factor in AHP (analytical hierarchy process) and identification coefficient in GRA (grey correlation analysis) is developed to implement the evaluation process in section III. Hereafter, section IVillustrates the evaluation process and results of manufacturing industry competiveness of six provinces in central China on the assessment indicator system and the simulation approach.Finally, in section V, some conclusions and limitations for this work are summarized and pointed out aimed at our data and approach.

II. Current Summary of Manufacturing Industry in Central China

We collect statistics data concerned with manufacturing competitiveness for six provinces in central China including scale, research and development, economical efficiency and ecology benefit during recent five years.

2.1Scale

Scale data includes corporate number, manpower and market share. Here, limited to space, only corporate number is given as Fig 1. As seen from Fig 1, it shows a large scale in six provinces except Shanxi.
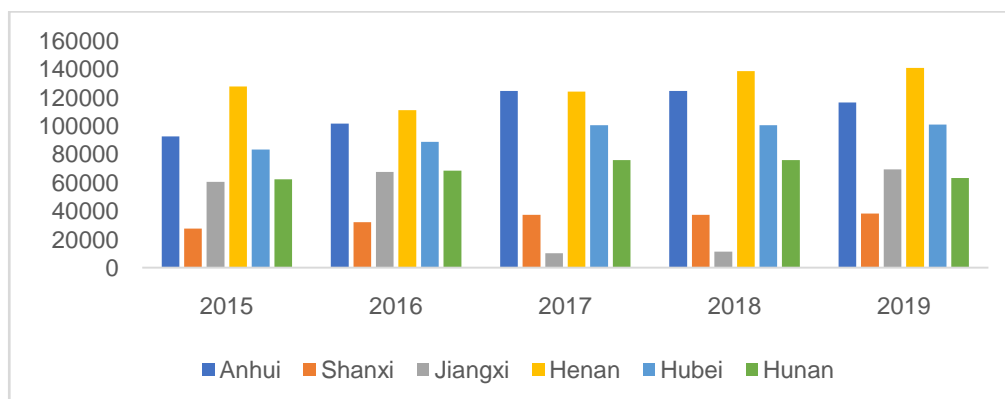

Fig 1: Corporate number of six provinces in central China

2.2 Research and Development

We collect R&D data which includes input and output of six provinces. Also, we just provide two types of R&D: patent approval rate and R&D ratio of input to sales revenue (unit is %).
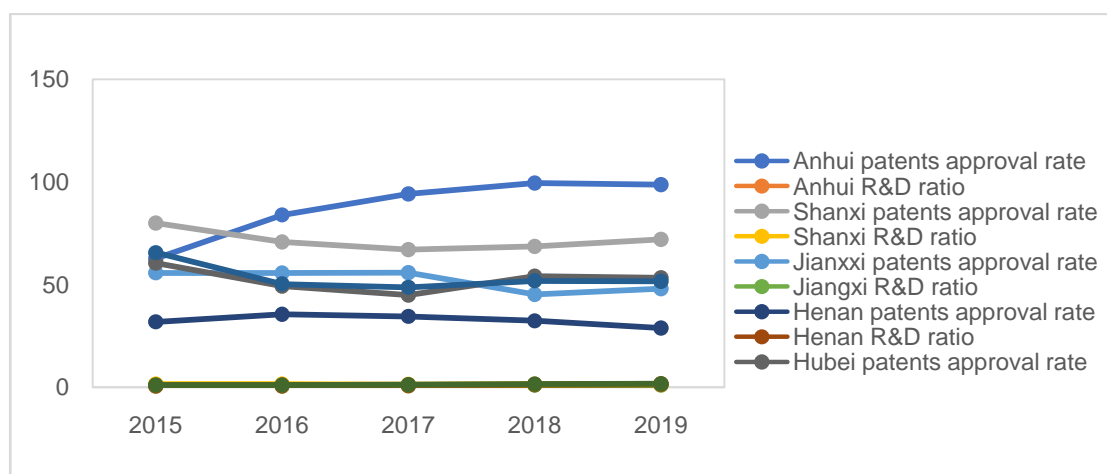
Fig 2: R&D input and output of six provinces in central China

From Fig 2, it can be seen that Anhui and Shanxi have an advantage over other four provinces in patent approval rate. While, in R&D input, these six provinces seem nearly the same.

2.3Economicefficiency

Economic efficiency data include investment in fixed assets, operation rate, products qualified rate, profit rate on cost, total asset contribution rate, asset-liability ratio input, main business income-cost ratio and main business income increasing rate etc.We depict them in Fig. 3 followed.

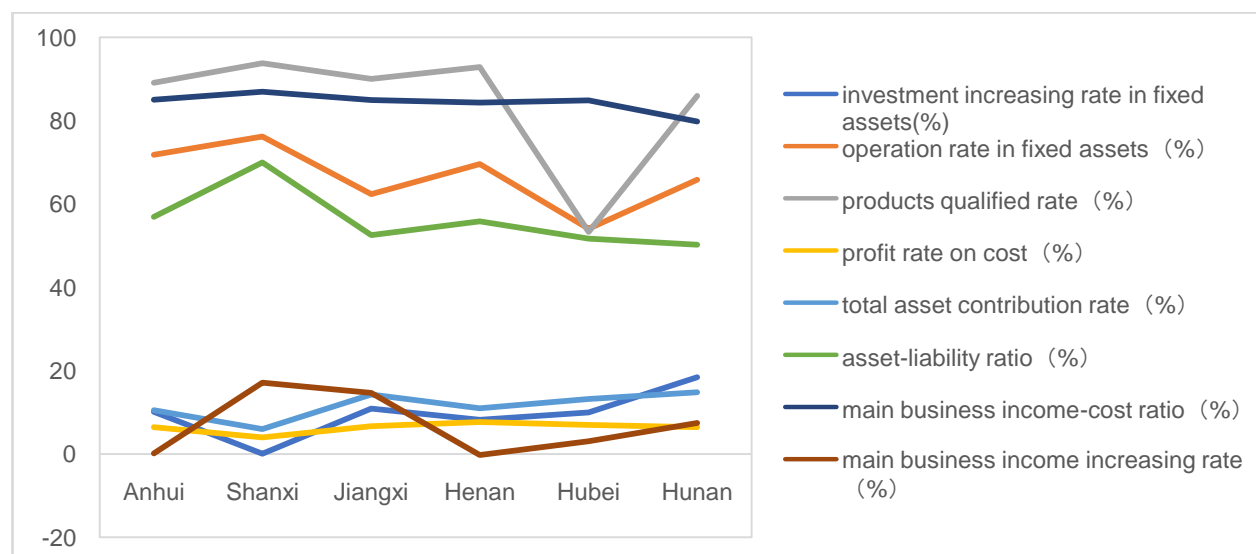*Fig 3: Economical efficiency of six provinces in central China*

As seen from Fig. 3, it shows that Jiangxi has some relative potency compared to other five provinces, while products qualified rate in Hubei seems lower.

2.4Ecology benefit

Fig. 4 shows ecology benefit data which are concerned with exhaust emission, waste water production, solid wastes output and investment on industry pollution etc.
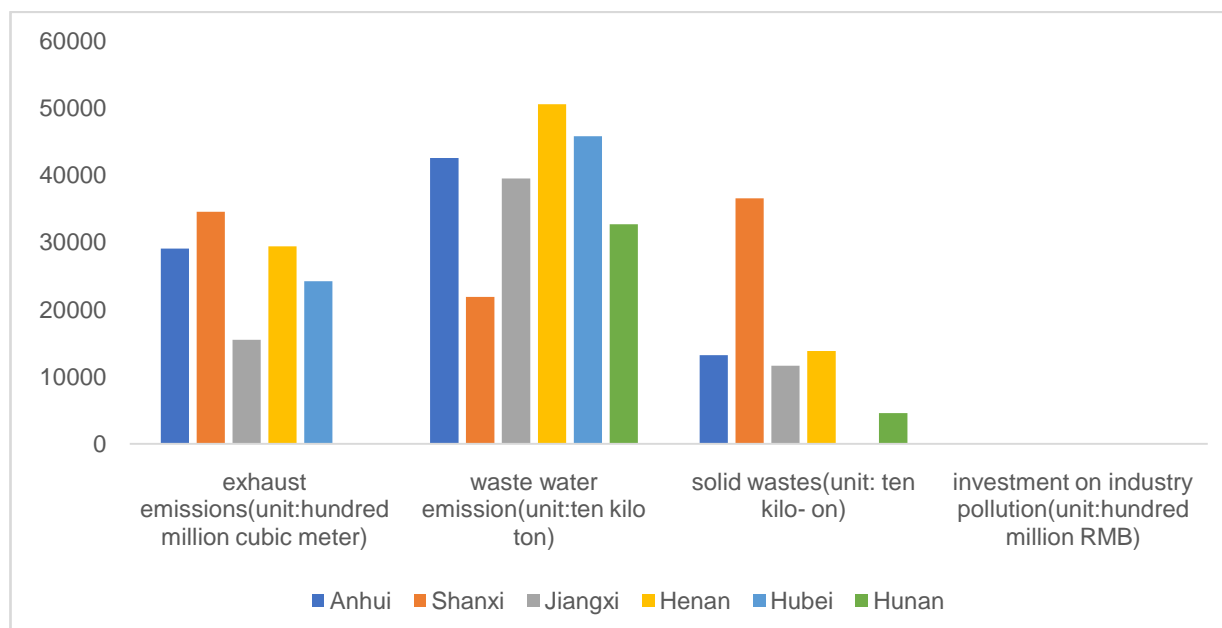
Fig 4: Ecological benefits of six provinces in central China

As seen from Fig. 4, ecology benefit for Shanxi is inferior to other provinces as a whole, while Jiangxi is on the contrary.

III. Evaluation Indicator System and Approach of Manufacturing industry

In this section, we attempt to construct an evaluation indicator system and develop a more reliable simulation approach for the assessment of manufacturing industry competitiveness. Simultaneously, in order to get a more reliable evaluation, a simulation approach considering uncertainty of weight in AHP and identification coefficient in GRA is developed based on AHP and GRA.

3.1Evaluation indicator system proposed

Since there is not a clear and unified assessment standard for the manufacturing industry competitiveness, an evaluation indicator system framework as shown in Table 1 is constructed based on SCP paradigm in industrial organizational theory, taking central China location and manufacturing industry characteristics, other experts and scholars' opinions into consideration.

Table 1 Evaluation indicator system for manufacturing industry competitiveness of central China

First level indicator	Second level indicator	Specific indicator	Unit
Economic efficiency	Asset factors	investment increasing rate of fixed assets	%
		operation rate of fixed assets	%
		products qualified rate	%
		profit rate on cost	%
	Economics factors	total asset contribution rate	%
		,asset-liability ratio	%
		main business income-cost ratio	%
		main business income increasing rate	%
Scale efficiency	Quantity factors	total population in the year	ten thousand
		number of manufacturing corporate	individual

		number of industrial enterprises above the designated size	individual
		manpower in manufacturing industry	ten thousand
	Market factors	market share	%
R&D efficiency	R&D input	proportion of R&D to manufacturing industry in the manpower	%
		proportion of R&D to whole country in the manpower,	%
		proportion of R&D expenditure to whole country in the cost	%
	R&Doutput	patent approval rate	%
		R&D ratio of input to sales revenue	%
Ecology efficiency	Pollution factors	exhaust emissions	hundred million cubic meter
		waste water production	ten kilo-ton
		solid wastes output	ten kilo-ton%
	Treatment	investment on industry pollution	hundred million RMB

3.1.1 Economic efficiency

Economic efficiency is a key element to embody manufacturing industry competitiveness, which can be depicted from two dimensions. One is concerned with assets including investment increasing rate of fixed assets, operation rate of fixed assets, products qualified rate and profit rate on cost. The other is relevant to economics factors including total asset contribution rate, asset-liability ratio,main business income-cost ratio and main business income increasing rate etc.

3.1.2 Scale efficiency

For the sake of scale efficiency, quantity and market share indicators are utilized to show manufacturing industry competitiveness. For quantity indicators, total population, manufacturing corporate numbers, numberof industrial enterprises above the designated size and manpower in manufacturing industry. For market factor, marker share is selected as a specific indicator.

3.1.3 R&D efficiency

In the long term, research and development have an impact on manufacturing core competence. We take R&D input and output to measure manufacturing industry competitiveness. For R&D input, proportion of R&D to manufacturing industry in the manpower, proportion of R&D to whole country in the manpower, proportion of R&D expenditure to whole country in the cost are selected as indicators. Patent approval rate andR&D ratio of input to sales revenue arecandidates for R&D output indicators.

3.1.4 Ecology efficiency

Along with sustainability acknowledged more and more, low carbon and green production are gradually awakened to promote manufacturing industry competitiveness. In our evaluation indicator system, ecology efficiency are measured from pollution and treatment dimensions. For pollution dimension, exhaust emissions, waste water production and solid wastes output are specific indicators. And investment on industry pollution is chosen for treatment dimension.

3.2 Simulation approach based on AHP and GRA

On the basis of evaluation indicator system, a novel simulation approach using AHP and GRA is developed to assess manufacturing competitiveness of six provinces in central China. In this novel simulation approach, we consider uncertainty on weight of AHP and identification coefficient of GRA. Steps of this simulation approach is depicted as follows;

Step1: Collect the original data of evaluation objects according to evaluation indicator system and normalize data

since the data's units are different.

Step2: Decide the weights of indicatorsω_i using AHP. Different from a unique weight for an indicator, this novel approach considers weight as a random variable which has a probability distribution so that grey correlation coefficient can be computed as a sample.

Step3: Set simulation times.

Step4: Compute grey correlation coefficient using the following formulas.

$$\xi_i(k) = \frac{a + \rho b}{|x_0(k) - x_i(k)| + \rho b}$$

$$a = min_s min_t |x_0(t) - x_s(t)|$$
$$b = max_s max_t |x_0(t) - x_s(t)|$$

$\rho \in [0,1]$

Here, $\xi_i(k)$ is termed by correlation coefficient of a comparative series $x_i(k)$ to the reference series$x_o(k)$ on the indicator k. Parameter a, b is called two level minimum difference, two level maximum difference respectively. Parameter ρ called identification coefficient is considered to be a uniform random variable in this approach.

Step5: Compute weighted grey correlation degree using the following formula, ranking the evaluation objects.

$$r_i = \sum_{k=1}^{n} \omega_i \xi_i(k)$$

Step6: Repeat step4-step5 until simulation times are reached.

Step7: Output simulation results such as the rank percentage for evaluation objects.

IV. Empirical Study of Manufacturing Industry Competitiveness for six Provinces in Central China

According to evaluation indicator system and the novel simulation approach proposed in the above section, we make an empirical study of manufacturing industry competitiveness for six provinces in central China. The original data are collected from China Statistical Yearbook, China Environment Statistical Yearbook, China Industrial Economics, Yearbook and regional yearbooks of six provinces in central China from 2015 to 2019.

4.1Standardized evaluation indicator data

The standardized evaluation indicator data for six provinces in central China are given in Table 2, using formula: $\frac{x_i - \mu}{\sigma}$(μis mean of x, σis standard deviation of x).

Table 2Standardized data for six provinces in central China

Indicator	Anhui	Shanxi	Jiangxi	Henan	Hubei	Hunan
1	0.09009	0.16349	-0.05159	-0.10317	-0.07168	-0.14351
2	0.08790	0.16825	-0.04875	-0.10134	-0.06990	-0.14052
3	0.08728	0.16936	-0.04722	-0.10065	-0.06993	-0.13925
4	0.09022	0.16373	-0.05182	-0.10319	-0.07181	-0.14426
5	0.09008	0.16386	-0.05140	-0.10309	-0.07156	-0.14373
6	0.08843	0.16787	-0.04929	-0.10175	-0.07000	-0.14150
7	0.08743	0.16893	-0.04750	-0.10090	-0.06866	-0.13964

8	0.09045	0.16456	-0.05138	-0.10343	-0.07197	-0.14420
9	0.16276	0.39719	0.20535	0.22347	0.16753	0.31673
10	4.05486	2.55366	3.76676	4.09783	4.00904	3.83314
11	0.49799	0.46419	0.65026	0.39912	-0.00223	0.89933
12	-0.08591	0.17097	-0.02247	-0.06935	-0.05845	-0.11773
13	-0.08985	0.16384	-0.05129	-0.10275	-0.07125	-0.14355
14	-0.08994	0.16364	-0.05209	-0.10336	-0.07188	-0.14444
15	-0.09031	0.16353	-0.05204	-0.10328	-0.07194	-0.14445
16	-0.09031	0.16354	-0.05206	-0.10329	-0.07192	-0.14440
17	-0.09039	0.16356	-0.05213	-0.10338	-0.07203	-0.14456
18	-0.08694	0.16799	-0.04954	-0.10256	-0.06993	-0.14142
19	-1.12563	-2.30424	-0.90874	-0.98211	-1.05210	-0.14739
20	-1.60504	-1.08458	-2.23546	-1.61376	-1.92567	-2.20622
21	-0.55991	-2.67949	-0.69601	-0.51692	-0.07210	-0.43413
22	-0.08949	0.16615	-0.05160	-0.10215	-0.07155	-0.14432

4.2 Weight computation using AHP

We use analytical hierarchy process (AHP) to compute weight as depicted in Table 3. For simplicity, we only assume the probability distribution of first level indicator weight. The uniform distributions is [0.24,0.30], [0.12,0.20], [0.42, 0.50], [0.05, 0.12] for economic, scale, R&D and ecology efficiency respectively.

Table 3 Indicators' weight for manufacturing industry competitiveness

First level indicator	Weight	Second level specific indicator	Sub-weight	Synthesized weight
Economic efficiency	0.277	investment increasing rate of fixed assets	0.0909	0.02519
		operation rate of fixed assets	0.0909	0.02519
		products qualified rate	0.1818	0.05039
		profit rate on cost	0.1818	0.05039
		total asset contribution rate	0.0909	0.02519
		,asset-liability ratio	0.0909	0.02519
		main business income-cost ratio	0.0909	0.02519
		main business income increasing rate	0.1818	0.05039
Scale efficiency	0.161	total population in the year	0.08895	0.01433
		number of manufacturing corporate	0.1579	0.02543
		number of industrial enterprises above the designated size	0.29762	0.04794
		manpower in manufacturing industry	0.1579	0.02543
		market share	0.29762	0.04794
R&D efficiency	0.466	proportion of R&D to manufacturing industry in the manpower	0.15387	0.07168
		proportion of R&D to whole country in the manpower,	0.08808	0.04103
		proportion of R&D expenditure to whole country in the cost	0.08808	0.04103
		patent approval rate	0.25709	0.11976
		R&D ratio of input to sales revenue	0.41288	0.19233
Ecology efficiency	0.096	exhaust emissions	0.2	0.01919
		waste water production	0.2	0.01919
		solid wastes output	0.2	0.01919
		investment on industry pollution	0.4	0.03839

4.3 Grey correlation coefficient computation using GRA

Using grey correlation analysis method, we compute a sample of grey correlation coefficients for six provinces in central China in Table 4 (identification coefficient ρ is set 0.5). The reference series is the optimal one in evaluation indicator system and the comparative series are six provinces' indicators.

Table 4Grey correlation coefficients of six provinces in central China

Indicator	Jiangxi	Shanxi	Henan	Hubei	Hunan	Anhui
1	1	1	1	1	1	1
2	0.998	0.998	1	0.999	0.999	0.999
3	0.997	0.998	1	0.999	0.999	0.999
4	1	1	1	1	1	1
5	1	1	1	1	1	1
6	0.998	0.999	1	0.999	0.999	0.999
7	0.997	0.998	1	0.999	0.999	0.999
8	1	1	1	1	1	1
9	0.888	0.897	0.944	0.939	0.943	0.952
10	0.333	0.427	0.568	0.422	0.792	0.488
11	0.705	0.859	0.917	0.946	0.847	0.857
12	0.985	0.992	0.994	0.999	0.999	0.996
13	0.999	1	1	1	1	1
14	1	1	1	1	1	1
15	1	1	1	1	1	1
16	1	1	1	1	1	1
17	1	1	1	1	1	1
18	0.999	0.998	1	0.999	1	0.999
19	0.616	0.635	0.756	0.659	1	0.686
20	0.403	0.714	0.692	0.536	0.699	0.625
21	0.681	0.602	0.868	1	0.929	0.828
22	1	0.999	1	1	1	1

4.4Weight grey correlation coefficient computation

Using weight of every indicator, weight grey correlation degree is computed 5000 times.Simulation results are summarized in Table 5(identification coefficient ρ is assumed a triangle distribution [0.4, 0.5, 0.7]).

Table 5Competitiveness ranking summarization six provinces in central China

			Jiangxi	Shanxi	Henan	Hubei	Hunan	Anhui
Economic efficiency	mean		0.9988	0.9992	1	0.99965	0.99964	0.99963
	rank	1	0.00%	0.00%	80.00%	10.26%	6.52%	3.22%
		2	0.00%	0.00%	16.24%	44.42%	27.18%	12.16%
		3	0.08%	0.04%	3.40%	34.70%	41.70%	20.08%
		4	1.82%	2.20%	0.36%	10.62%	24.28%	60.72%
		5	38.38%	57.76%	0.00%	0.00%	0.28%	3.58%
		6	59.72%	40.00%	0.00%	0.00%	0.04%	0.24%
Scale efficiency	mean		0.79424	0.85713	0.90115	0.88706	0.91638	0.87169
	rank	1	0.00%	0.00%	14.52%	6.54%	78.18%	0.76%
		2	0.00%	0.02%	54.44%	21.36%	17.12%	7.08%
		3	0.00%	0.02%	25.82%	46.74%	4.28%	23.14%
		4	0.00%	2.74%	5.22%	25.24%	0.42%	66.38%
		5	0.00%	97.22%	0.00%	0.12%	0.00%	2.64%
		6	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%

R&D efficiency	mean		0.9996	0.9992	1	0.9996	0.9999	0.99963
	rank	1	2.42%	0.00%	84.20%	0.16%	7.78%	5.44%
		2	12.52%	0.00%	13.52%	5.90%	41.94%	26.12%
		3	17.92%	0.00%	2.06%	14.22%	30.22%	35.58%
		4	29.58%	0.08%	0.22%	29.36%	15.72%	25.04%
		5	37.08%	1.06%	0.00%	49.70%	4.34%	7.82%
		6	0.48%	98.86%	0.00%	0.66%	0.00%	0.00%
Ecology efficiency	mean		0.74	0.7898	0.8632	0.839	0.9256	0.8278
	rank	1	0.00%	0.00%	4.60%	0.02%	95.38%	0.00%
		2	0.00%	0.00%	77.78%	14.66%	4.58%	2.98%
		3	0.00%	0.24%	13.50%	71.90%	0.04%	14.32%
		4	0.00%	8.28%	4.04%	13.42%	0.00%	74.26%
		5	9.42%	82.06%	0.08%	0.00%	0.00%	8.44%
		6	90.58%	9.42%	0.00%	0.00%	0.00%	0.00%
Comprehensiveevaluation	mean		0.94138	0.95619	0.97094	0.96602	0.97923	0.96245
	rank	1	0.00%	0.00%	3.12%	14.88%	72.24%	9.76%
		2	0.00%	0.00%	30.24%	30.56%	22.36%	16.84%
		3	0.00%	0.00%	43.02%	33.70%	4.88%	18.40%
		4	0.40%	2.20%	23.62%	20.86%	0.52%	52.40%
		5	21.86%	75.58%	0.00%	0.00%	0.00%	2.56%
		6	77.74%	22.22%	0.00%	0.00%	0.00%	0.04%

From Table 5, it can be seen that Henan shows an advantage in economics and R&D efficiency, while Hunan is predominant in scale and ecology efficiency. Hubei and Anhui have potentials to compete in economics efficiency and scale efficiency. As for Jiangxi and Shanxi, there are good spaces of promotion either in economics efficiency or scale efficiency. On the whole, the ranking of comprehensive competitiveness on manufacturing industry is ordered by Hunan, Henan, Hubei, Anhui, Shanxi and Jiangxi.

V. Conclusion

With rapid development of social economy in China, six provinces in central China is playing more and more important parts in linking south and north, east and west. Manufacturing industry is considered to be a critical sector in economic system and makes a difference between developing region and developed region. In this paper, using SCP paradigm and weighted grey correlation method, we construct an evaluation indicator system for manufacturing industry and propose a novel simulation approach considering uncertainty of weight in AHP and identification coefficient of GAR. Taking six developing provinces in central China for example model, an empirical study on manufacturing industry competitiveness is carried out and simulation results reveal that Hunan and Henan have some advantages in economics and scale efficiency, while Jiangxi and Shanxi need to upgrade their manufacturing industry in scale and ecology efficiency. Limited to data availability and evaluation methods, further research includes a more appropriate evaluation indicator system, much more data and evaluation approaches.

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