Industrial structure optimization in central China under the energy constraint

SUN Wei^{1,2}, LI Wenhui^{1,2,3}, TANG Zhipeng^{1,2}, *FAN Jie^{1,2}

1. Institute of Geographical Sciences and Natural Resources Research, CAS, Beijing 100101, China;

2. Key Laboratory of Regional Sustainable Development Modeling, CAS, Beijing 100101, China;

3. University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Optimizing industrial structure is an important research object of human-economic geography, and it is also the object of government departments to strengthen macro-control. This has become even greater problem that China has entered the “new normal” in recent years. The study uses a multi-regional input-output model, with linear programming to build an optimal model of industrial structure as well as a model of optimization degree under the energy constraint. The results of the study revealed that: (1) the degree of optimization of industrial structure in Anhui Province is optimal (0.763), while that of Shanxi Province is the lowest (0.662); (2) the degree of optimization of industrial structure is negatively related to energy consumption per unit output value and the proportion of heavy industry; and (3) overall, central China should maintain or moderately increase the proportions of resource-based industry, greatly increase the proportions of manufacturing, including transport and telecommunications equipment, computers and other electronic equipment, and moderately reduce the proportions of smelting and pressing of metals and non-metal mineral products. In terms of service industries, the region should greatly increase the proportions of the production and supply of natural gas and tap water, moderately reduce or maintain the proportions of transport and storage as well as tourism, and maintain or moderately reduce the proportions of wholesale trade, retail trade and catering services.

Keywords: central China; multi-regional input-output model; linear programming; industrial structure; energy consumption

1 Introduction

Industrial structure is a term that describes the composition among and within various industrial sectors, which is commonly used for both industrial and regional economic analysis (Gao and Li, 2006; Gan *et al.*, 2011; Liu and Li, 2002). Optimizing industrial structure is not only frequently mentioned in human-economic geography studies and government documents, but is also a scientific issue that is important and realistic. The current development

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Author: Sun Wei (1975–), Associate Professor, specialized in regional sustainable development and spatial planning.

E-mail: sunw@igsnr.ac.cn

***Corresponding author:** Fan Jie, Professor, E-mail: fanj@igsnr.ac.cn

model in China based on the characteristics of sustained and rapid growth is difficult to maintain, facing as it does a range of resource and environmental issues such as energy security and international standards for emissions reduction (Liu *et al.*, 2010; Liu *et al.*, 2012). Increasing energy efficiency, optimizing energy structure and promoting national energy conservation and emissions reduction should form the core of China's sustainable energy strategy in the future, among which the key component of increasing energy efficiency depends on industrial structure adjustment and technological progress (Fan *et al.*, 2015; Liu *et al.*, 2012). There is great potential for China to achieve energy conservation and emissions reduction goals by 2020 as a result of industrial structure adjustment (Fan *et al.*, 2015; Wang and Xiang, 2014). Therefore, realizing the goal of energy conservation and emissions reduction by optimizing industrial structure becomes an important issue for regional science research and governmental macroeconomic management.

However, a systematic solution based on a quantitative approach has so far not yielded a scientific answer to the question of how to optimize industrial structure. According to the literature, most studies have described the direction of optimization of industrial structure, which was mainly based on Petty-Clark's Law, from the perspective of primary, secondary and tertiary industries (He and Yao, 2008; Qiu and Fang, 2010). The structure of these industries involves few industrial sectors, and this largely limits the practical guidance that may be gained from a study of them. Thus it is necessary to carry out further studies to include more industrial sectors. Existing studies, meanwhile, provide mainly qualitative analysis (He *et al.*, 2014; Zhang, 2010), from which it is difficult to derive a practical plan from a relative lack of quantitative data. Willett (1985) developed a general equilibrium model to identify the economic effects of pollution control policies. To make the trade-offs between environmental quality and economic growth, Luptáček and Böhm (1994) constructed an environmental input-output optimization model under the constraint of multi-goals, the constraint standards of which were the minimization of GDP at factor cost and net contamination under the specific final demand level. Jiang and Liang (2000) introduced an integrated model of sustainable water resources planning and application, with examples. Wang *et al.* (2001) found that sustainable development in China as a whole is possible if the industrial structure is adjusted to achieve the level of industrial structure in Beijing. Tang *et al.* (2012) constructed five periods of the input-output optimization model for Beijing using the regional input-output tables for the city for the period from 1987 to 2007 under the constraint of energy consumption, realizing the maximization of economic benefits by adjusting the industrial structure and putting forward the adjustment direction for the industrial structure for the future. Yan and Jia (2009) combined the analytic hierarchy process with the linear programming method to study the optimal allocation of water resources for economic development in Hebei Province in 2010, based on the input-output structure of water resources, and developed four sets of industrial structural adjustment programs with comparative analysis of each. Liu *et al.* (2010) used the carbon emission coefficient of different industries across several provinces and established the CO₂ emissions model for China's regional industrial structure adjustment based on the inter-regional input-output table, analyzing the effect of reduction of various industries in different regions.

The studies mentioned above focused mainly on water resource or environmental constraints. There are fewer studies on regional industrial structure optimization carried out un-

der the energy constraint. In these studies, most researchers have focused on a single region, which easily overlooks mutual contact and interaction with other regions, and thus transfers the so-called high-energy, no-profit “bad” industries to other regions to pursue their own optimization, falling into a failure of local optimization but overall situation is not optimal. Therefore, factor mobility between regions must be considered in order to achieve overall optimal in multiple regions. Accordingly, this paper has applied a multi-regional input–output model and has combined linear programming to construct the overall optimal model of industrial structure under the energy constraint, which helps central China to further adjust its industrial structure and achieve energy conservation as well as provide a scientific basis for formulating and perfecting supportive policies.

2 Data sources and research methods

Central China comprises six provinces, including Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan, with a land area of 1.0166 million km², a population of 361 million people and a GDP of 12.730 trillion yuan, which created 22.4% of total GDP with 10.6% of China’s total land area and 26.5% of total population (Table 1). It is a region of population agglomeration and an economic hinterland and important market which plays an important role in the pattern of geographical division of China.

Table 1 Overview of central China

Indicator	Total	Proportion (%)	Indicator	Total	Proportion (%)
Land area (10 ⁴ km ²)	101.66	10.59	Profits of industrial enterprises (trillion yuan)	1.21	19.32
Population (100 million)	3.61	26.52	Persons employed in urban (100 million)	1.81	21.00
Urban population (100 million)	1.75	23.93	Total investment in fixed assets (trillion yuan)	10.57	23.69
GDP (trillion yuan)	12.73	22.38	Non-agriculturalization rate (%)	0.88	98.01
Industrial value added (trillion yuan)	2.11	27.48	Local public fiscal revenue (trillion yuan)	1.20	17.44
Number of industrial enterprises above designated size (10,000)	35.25	20.76	Disposable income of urban residents (yuan)	22736	84.35
Per capita GDP (yuan)	35279	84.39	Rural per capita net income (yuan)	8377	94.16

Note: The data for land area are from *The Administrative Divisions of The People’s Republic of China* (2014). Per capita GDP is the total GDP of the six provinces divided by their total population. Disposable income of urban residents, rural per capita net income and non-agriculturalization rate are calculated in the same way as Per capita GDP.

2.1 Data sources

The data for the total energy consumption of six provinces in central China were obtained from the *China Statistical Yearbook* for 2011. Total energy consumption is divided between 45 different branches of industry. These 45 industrial sectors were merged into 27 branches to make the results clearer and to take the standard industrial classification of input-output tables in 2010 into consideration, as shown in Table 2.

Table 2 Industrial sectors of the national economy in central China and their codes

Code	Industrial sector	Code	Industrial sector
1	Farming, forestry, animal husbandry and fisheries	15	Metal products
2	Coal mining and dressing	16	General and special-purpose equipment
3	Petroleum and natural gas extraction	17	Transport equipment
4	Minerals mining and dressing	18	Electrical equipment and machinery
5	Non-metal and other minerals mining and dressing	19	Telecommunications equipment, computers and other electronic equipment
6	Food production and tobacco processing	20	Instruments, meters, cultural and office machinery
7	Textile industries	21	Other manufactures
8	Textiles, garments, footwear, caps, leather, down and related products	22	Production and supply of electric power and heat power
9	Timber processing and furniture manufacturing	23	Production and supply of gas and tap water
10	Papermaking, printing and cultural, educational and sports goods	24	Construction industries
11	Petroleum processing, coking and nuclear fuel processing	25	Transport and storage
12	Chemical industries	26	Wholesale trade, retail trade and catering services
13	Non-metal mineral products	27	Other services
14	Smelting and pressing of metals		

The work of surveying and tabulating the national input-output tables for China was begun in 1978. The relevant table for 2010 is the latest one available, so this year was selected for study (Liu *et al.*, 2015).

2.2 Research methods

Input-output analysis is a powerful tool for regional modeling, and input-output tables can reflect the objective annual economic structure of a region in detail, which has been widely used in many countries around the world. The essence of optimization is a process of approaching along the established development goals in the seeking path, and this goal is specific rather than vague. This demonstrates that optimizing industrial structure is clearly goal-oriented, and so optimizing it according to different goals must take a different approach. Therefore, energy conservation is set as the goal-orientation based on the preceding analysis, applying the multi-regional input-output model and linear programming to construct the optimal model of industrial structure oriented to energy conservation in central China and the optimization degree model.

2.2.1 Optimal model of industrial structure

The objective function is defined as

$$\max \quad z = \sum_p A_v^p X^p \tag{1}$$

and the constraint conditions are

$$\text{s.t.} \quad \begin{cases} AX + F + U \leq X \\ \sum_p A_E^p X^p \leq \bar{E} \\ X^L \leq X \leq X^H \\ U^L \leq U \leq U^H \end{cases} \tag{2}$$

The proportion of optimized industrial structure in each region is

$$\eta_i^p = x_i^p / \sum_i x_i^p (i = 1, \dots, 27; p = 1, \dots, 6) \quad (3)$$

The proportion of adjusted industrial structure in each region is

$$\Delta_i^p = \eta_i^p - \tau_i^p (i = 1, \dots, 27; p = 1, \dots, 6) \quad (4)$$

The variables in the above model are the target function z in Eq. (1) which is the maximization of the total GDP simulation value of the six provinces, and shows that the economic benefit to central China is a maximum, A_i^p in Eq. (1) is a 1×27 vector of directly increased value coefficients of the 27 industrial sectors in P province according to the regional input-output table for 2010, X^p is a 1×27 vector of export simulation values to be solved in P province. They satisfy the constraint conditions of input and output in the multi-region economic system, and energy conservation, where A , U , X and F are, respectively, 162×162 matrix of direct consumption coefficients, a 162×1 export column vector, a 162×1 total output column vector and a 162×1 matrix of final demand in the input-output tables for the six provinces. F is set as the rigid invariant constant term in the model. $\bar{E}$ is the actual energy consumption of the six provinces and is the upper limiting value of energy consumption. The growth rate of GDP and export value in each province in that year and the previous year were set, respectively, as the upper and lower boundary constraints of X and U based on the GDP and export value in the current year, indicated by superscript L as the lower limit and superscript H as the upper limit. The upper and lower boundary constraints of X can be determined by the multi-regional input-output relationships. The proportion of the optimized value η_i^p in P province is determined finally by solving the proportion of the vector elements x_i^p within X^p in Eq.(3). Finally, Δ_i^p to be solved is the specific adjustment proportion according to τ_i^p , the actual proportion of the industrial structure in P province in Eq. (4).

2.2.2 Optimization degree model

After solving the proportion of the optimization value of industrial structure of P province in the above optimal model of industrial structure, it is necessary to compare the degree of similarity between the actual proportion $G^p(1)$ and the optimal proportion $G^p(0)$ of various sectors of industrial structure in P province. Although it is easy to measure the gap between the optimal and actual values of any single industry, the industrial structure reflects the overall situation of various industries, and so multiple industries must be taken as a whole to compare and measure the optimization degree. Comparing similar curves, grey relational grade analysis was applied to determine the degree of similarity between them in order to determine the degree of optimization of industrial structure in each province. Grey relational grade analysis can be summarized as follows:

Suppose the reference number series is $G^p(0)$ and the compared series is $G^p(1)$, then

$$G^p(0) = \{\eta_1^p(0), \eta_2^p(0), \dots, \eta_n^p(0)\}; G^p(1) = \{\eta_1^p(1), \eta_2^p(1), \dots, \eta_n^p(1)\}$$

While $R(G^p(0), G^p(1))$, which is the grey relational grade between $G^p(0)$ and $G^p(1)$ is defined as

$$R(G^p(0), G^p(1)) = \frac{1}{n} \sum_{k=1}^n r(\eta_k^p(0), \eta_k^p(1))$$

$$r(\eta_k^p(0), \eta_k^p(1)) = \frac{\min_k (\min_k |\eta_k^p(0) - \eta_k^p(1)|) + \rho \max_k (\max_k |\eta_k^p(0) - \eta_k^p(1)|)}{|\eta_k^p(0) - \eta_k^p(1)| + \rho \max_k (\max_k |\eta_k^p(0) - \eta_k^p(1)|)} \quad (5)$$

where ρ is the discrimination coefficient in the interval $0 \leq \rho \leq 1$, generally taking $\rho=0.5$.

3 Optimizing industrial structure under the energy constraint

Central China is a concentrated area of energy consumption which in 2010 amounted to 843.26 million tonne of coal equivalents (tce) and accounted for 27.38% of national energy consumption. According to the comprehensive plan for energy conservation and emissions reduction in the 12th Five-Year Plan and for promoting the development of central China, achieving these goals is still a long way off. The growth in economic output of P province is calculated according to its optimal economic output (g^p) and its actual economic output ($\tilde{g}^p$). Using the geometric mean method, first the economic output growth of central China (λ) is calculated. The study shows that the economic output of this region increased by 24.13% through optimizing the industrial structure on the premise of unchanged energy consumption.

$$\lambda = \sqrt[p]{\prod_{p=1}^6 (g^p / \tilde{g}^p - 1)} \tag{6}$$

3.1 Degree of optimization of industrial structure

Using grey relational grade analysis to compare the degree of similarity between the actual and optimal proportions of the 27 industrial sectors in P province, the results show that the optimization degree of industrial structure in Anhui Province is optimal. The results for Hunan, Jiangxi, Henan and Hubei provinces had lower values, and that for Shanxi Province was the lowest of all (Table 3).

Table 3 Industrial structure optimization of six provinces in central China under the energy constraint

	Shanxi	Anhui	Jiangxi	Henan	Hubei	Hunan
Optimization degree of industrial structure	0.662	0.763	0.755	0.752	0.704	0.760

SPSS20.0 software and the Pearson correlation coefficient were used in the analysis of the data. The results of the study show that the degree of industrial structure optimization has a significant correlation with energy efficiency and the proportion of heavy industry (Table 4).

Table 4 Pearson correlation analysis of industrial structure optimization under the energy constraint

	Energy consumption per unit of GDP (tce/10,000 yuan)	Energy consumption per unit of industrial added value (tce/10,000 yuan)	Proportion of heavy industry output value (%)
Pearson correlation coefficient	-0.879*	-0.890*	-0.887*
Significance (2-tailed)	0.021	0.018	0.018
N	6	6	6

Note: * indicates significance at the 5% level, ** indicates significance at the 1% level.

Analysis shows that the energy consumption per unit of GDP of Jiangxi Province was slightly below the national average in 2010. Energy consumption per 10,000 yuan of GDP declined from 1.06 tce in 2005 to 0.67 tce in 2010 and was 4.29 percentage points lower than the national average (Table 5). The energy consumption per unit of industrial added

value for Shanxi Province was above the national average in 2010, ranking second behind Ningxia Hui Autonomous Region. According to the Pearson correlation analysis, the higher the energy consumption per unit of GDP and per unit of industrial added value, the lower the degree of industrial structure optimization.

Table 5 Energy consumption per unit of GDP and industrial added value in six provinces of central China

	2005		2010	
	Energy consumption per unit of GDP (tce/10,000 yuan)	Energy consumption per unit of industrial added value (tce/10,000 yuan)	Energy consumption per unit of GDP (tce/10,000 yuan)	Energy consumption per unit of industrial added value (tce/10,000 yuan)
Shanxi	2.95	6.50	1.83	3.66
Anhui	1.21	3.13	0.79	1.83
Jiangxi	1.06	3.11	0.67	2.05
Henan	1.38	4.02	0.93	2.17
Hubei	1.51	3.50	0.95	2.47
Hunan	1.40	2.88	0.93	2.51
Central China	—	—	0.98	2.41
China	1.22	2.59	0.70	1.92

Data source: calculated according to the *China Statistical Yearbook* of 2006 and 2011.

Analysis based on the internal structure of light and heavy industries shows that the proportions of heavy industry in Henan, Jiangxi, Anhui and Hunan provinces are below the national average (71.36%), while that of Shanxi Province is 94.62%, which is much higher than the national average (Table 6). Central China is in the early stages of processing resources. Energy and raw materials-based industries such as coal, electricity, metallurgy and building materials account for a large proportion of the energy used. On the premise of broadly consistent technological levels, the proportion of heavy industry largely determines the level of energy consumption. According to Pearson correlation analysis, the higher the proportion of heavy industry, the lower the degree of industrial structure optimization.

Table 6 Percentage of light and heavy industries in six provinces in central China in 2010

	Light industry output value		Heavy industry output value	
	Absolute value (100 million yuan)	Percentage (%)	Absolute value (100 million yuan)	Percentage (%)
Shanxi	671.28	5.38	11800.06	94.62
Henan	10601.23	30.29	24394.30	69.71
Anhui	5566.43	29.72	13165.57	70.28
Jiangxi	4143.19	29.84	9739.88	70.16
Hunan	5477.86	28.82	13530.97	71.18
Hubei	5935.78	27.45	15687.33	72.55
Central China	32395.77	26.84	88318.11	73.16
China	200071.53	28.64	498519.01	71.36

Data source: calculated according to the *China Industrial Economy Statistical Yearbook* of 2011.

3.2 Provincial differences in industrial structure optimization

Despite the six provinces in central China being strongly consistent in their endowment of resources, traffic location, levels of economic development and stage of industrialization, there still exist some differences in the level of optimization of industrial structure under the energy constraint (Figure 1).

Figure 1 Differences between actual and optimal values of industrial structure in six provinces of central China

Table 7 Codes of optimized industrial sectors among six provinces in central China

Province	Greatly increased ($2.16\% \leq \Delta_i^p$ <5.16%)	Moderately increased ($0.18\% \leq \Delta_i^p$ <2.16%)	Essentially unchanged ($-2.60\% \leq \Delta_i^p$ <0.18%)	Moderately reduced ($-6.55\% \leq \Delta_i^p$ <-2.60%)	Greatly reduced ($-11.74\% \leq \Delta_i^p$ <-6.55%)
Shanxi	5, 9, 10, 13, 17, 18, 19, 20, 21	4, 6, 7, 8, 16, 23	1, 3, 11, 12, 15, 26	22, 24, 25, 27	2, 14
Anhui	4, 5, 10, 15, 19, 20, 21, 23	2, 3, 7, 8, 9, 11, 25	12, 13, 14, 16, 17, 18, 22, 26	1, 6	24, 27
Jiangxi	5, 15, 20, 21, 23	2, 3, 4, 7, 8, 9, 10, 11, 16, 17, 18, 19, 22, 25	1, 6, 13, 26	12, 27	14, 24
Henan	3, 19, 20, 23	2, 4, 5, 7, 8, 9, 10, 11, 15, 17, 18, 19, 21, 22, 25	12, 14, 26	1, 6, 13, 16, 24	27
Hubei	4, 5, 9, 11, 18, 19, 20, 21, 23	2, 3, 7, 8, 10, 15, 16, 17	13, 14, 25, 26	1, 6, 12, 22	24, 27
Hunan	4, 5, 7, 8, 15, 19, 20, 21, 23	2, 3, 9, 10, 17, 18, 22, 25	11, 12, 13, 16	1, 6, 14, 26	24, 27

According to the calculation results of Δ_i^p , industrial structure optimization can be divided into five types using natural breaks classification. The five types are: greatly increased ($2.16\% \leq \Delta_i^p < 5.16\%$), moderately increased ($0.18\% \leq \Delta_i^p < 2.16\%$), essentially unchanged ($-2.60\% \leq \Delta_i^p < 0.18\%$), moderately reduced ($-6.55\% \leq \Delta_i^p < -2.60\%$) and greatly reduced ($-11.74\% \leq \Delta_i^p < -6.55\%$) (Table 7).

4 Specific path of optimizing industrial structure

According to the calculation results, there exist certain differences between the paths of optimizing industrial structure of each province under the energy constraint. In order to illustrate the problem more clearly, the greatly increased and moderately increased classes are combined into a single increased class and the greatly reduced and moderately reduced are combined into a single reduced class. The top three industries in either the increased or reduced class of each province are then chosen to illustrate the path of optimizing the industrial structure. It should be noted that the top two industries in the essentially unchanged class were chosen because there were fewer industrial sectors.

4.1 Differences in the optimization path

The calculation results show that the optimal path for Shanxi Province under the energy constraint would be to reduce the proportions of coal mining and dressing, smelting and pressing of metals, as well as construction industries, to increase the proportions of telecommunications equipment, computer and other electronic equipment, instruments, meters, cultural and office machinery and other equipment manufacturing, and to keep the proportions of petroleum and natural gas extraction, petroleum processing, coking and nuclear fuel processing unchanged (Table 8).

Table 8 Codes of optimized industrial sectors among six provinces in central China

Province	Increased	Unchanged	Reduced
	$(0.18\% \leq \Delta_i^p < 5.16\%)$	$(-2.60\% \leq \Delta_i^p < 0.18\%)$	$(-11.74\% \leq \Delta_i^p < -2.60\%)$
Shanxi	19, 20, 21	3, 11	2, 14, 24
Anhui	5, 20, 23	13, 16	6, 24, 27
Jiangxi	20, 21, 23	1, 6	14, 24, 27
Henan	3, 19, 23	12, 26	6, 16, 27
Hubei	4, 20, 23	14, 25	1, 24, 27
Hunan	5, 20, 23	11, 13	1, 24, 27

Anhui Province should reduce the proportions of food production and tobacco processing, construction industry and other services, increase the proportions of non-metal and other minerals mining and dressing, instruments, meters, cultural and office machinery, production and supply of gas and tap water, and keep the proportions of non-metal mineral products and general and special purpose equipment unchanged.

Jiangxi Province should reduce the proportions of smelting and pressing of metals, construction industries and other services, increase the proportions of instruments, meters, cultural and office machinery, other manufactures and production and supply of gas and tap

water, and keep the proportions of farming, forestry, animal husbandry and fisheries, food production and tobacco processing unchanged.

Henan Province should reduce the proportions of food production and tobacco processing, general and special purpose equipment, and other services, increase the proportions of petroleum and natural gas extraction, telecommunications equipment, computers and other electronic equipment, and production and supply of gas and tap water, and keep the proportions of chemical industry, and wholesale trade, retail trade and catering services unchanged.

Hubei Province should reduce the proportions of farming, forestry, animal husbandry and fisheries, construction industries and other services, increase the proportions of minerals mining and dressing, instruments, meters, cultural and office machinery, and production and supply of gas and tap water, and keep the proportions of smelting and pressing of metals and transport and storage unchanged.

Hunan Province should reduce the proportions of farming, forestry, animal husbandry and fisheries, construction industries and other services, increase the proportions of non-metal and other minerals mining and dressing, instruments, meters, cultural and office machinery, and production and supply of gas and tap water, and keep the proportions of petroleum processing, coking and nuclear fuel processing and non-metal mineral products unchanged.

4.2 Overall optimal path for central China

4.2.1 Adjusting the primary industry appropriately

The traditional approach of expanding the agricultural scale to increase the agricultural added value is undesirable and the internal structure needs to be adjusted appropriately: by reducing the proportion of farming and increasing the proportion of fisheries, by developing forestry vigorously, by actively exploring high-quality agriculture suitable for each province, by promoting a fruit industry base in Jiangxi Province and a high-quality wheat base in Henan Province to achieve characteristics, scale and specialization, and by promoting agricultural industrialization vigorously and by increasing the added value of produce.

4.2.2 The greater internal difference of secondary industry

Central China is the energy and raw material base in China. The mining industries can make full use of local resources and their energy advantage so as to increase the proportion of the mining industries moderately. In the long term, however, excessive dependence on energy and resource industries is likely to bring about a single industrial structure and difficulties in transition to other types of industry. So the optimal path for the future is to keep the proportion of coal, petroleum, natural gas and other mining industries unchanged or perhaps slightly increased. The proportion of modern manufacturing, including telecommunications equipment, computers and other electronic equipment, instruments, meters, cultural and office machinery should be greatly increased. Manufactures of electrical equipment and machinery, transport equipment, general and special purpose equipment, and textile, garments, footwear, caps, leather, down and related products should be increased moderately. The proportions of heavy chemical industries, especially manufactures of metal products, non-metal mineral products, smelting and pressing of metals, production and supply of electric power and heat power should be reduced moderately. The proportions of petroleum processing, coking and nuclear fuel processing, production and supply of gas and tap water

should be increased moderately. Since the development of the construction industry also drives that of energy-intensive industries, its proportion should be reduced moderately.

4.2.3 Placing emphasis on key sectors of tertiary industry

Central China represents a national, integrated transport hub. Increasing the proportion of transport and storage helps to save energy. The proportions of transport and storage in Anhui, Jiangxi, Henan and Hunan provinces should be increased moderately. The proportions of wholesale trades, retail trades and catering services in central China should be kept unchanged or be reduced moderately. The calculation results show that the proportion of other services should be moderately reduced, but central China is a region with a long history and culture and possesses many historical sites, so the development of tourism can alleviate pressures on energy consumption to a certain extent.

5 Discussion and conclusions

The study shows that the economic output of central China increased by 24.13% through optimizing the industrial structure on the premise of unchanged energy consumption. The degree of optimization of industrial structure in Anhui Province is optimal (0.763), which of Hunan, Jiangxi, Henan and Hubei provinces follow, while that of Shanxi Province is the lowest (0.662). This degree is related to energy efficiency and the proportion of heavy industry. The higher the energy efficiency and the lower the proportion of heavy industry, the higher the degree of optimization of industrial structure.

As a whole, the proportions of farming, forestry, animal husbandry and fisheries in central China should be reduced moderately ($-6.55\% \leq \Delta_i^p < -2.60\%$), high-quality agriculture should be developed and the development road of scale expansion should be avoided. In terms of industry, the proportion of resource-based industries should be kept unchanged ($-2.60\% \leq \Delta_i^p < 0.18\%$) or increased moderately ($0.18\% \leq \Delta_i^p < 2.16\%$), while greatly increasing ($2.16\% \leq \Delta_i^p < 5.16\%$) the proportions of modern manufacturing industries, including telecommunications equipment, computers and other electronic equipment, transport equipment, electrical equipment and machinery. The proportions of smelting and pressing of metals, chemical industries and non-metal mineral products should be moderately reduced, while greatly reducing ($-11.74\% \leq \Delta_i^p < -6.55\%$) the proportion of construction industry. In terms of service industries, the proportion of production and supply of gas and tap water should be greatly increased, the proportions of transport and storage and of tourism should be moderately increased, while keeping the proportions of wholesale trades, retail trades and catering services unchanged or moderately reduced. The proportions of all other services should be greatly reduced.

It should be noted that optimizing industrial structure of central China should give priority to manufacturing industry, and most of the proportions of tertiary industries should be reduced according to the optimal model of industrial structure under the energy constraint. This is mainly because: (1) central China is still in the middle stage of industrialization and assumes the role of energy and raw materials base in China; (2) the service industries of central China are still in the low stage of development and in general does not have a comparative advantage with respect to manufacturing industry; and (3) restricted by the data, the services sector cannot be further subdivided and the potential services cannot be distinguished.

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