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Research on China's Industrial Green Development based on the Pressure-State-Response Model

Chu Chen, Kuan Wang and Mei Feng*

Donlinks School of Economics and Management, University of Science and Technology Beijing, No. 30, Xueyuan Road, Haidian District, Beijing, 100 083, PR China

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This study developed a system to evaluate China's industrial green development based on the Pressure-State-Response (PSR) model. After analyzing the unbalanced industrial green development among China's four major economic regions, the study found that strengthening technological research and development and brain gain is the key to promoting potential and inter-regional coordination for industrial green development.

Key words: PSR model, Industry, Green development, Economic regions

Introduction

China's Ministry of Industry and Information Technology issued the *Industrial Green Development Plan (2016–2020)* in 2016. The plan clearly pointed out that a long-term mechanism for industrial green development should be established and improved by focusing on the green transformation of traditional industries. From the perspective of input, output, and industrial structure, there is still a gap between China's industry and the world's leading industrialization level in terms of green and low-carbon technologies and industrial development.[1] Regional efficiency is still restricted by different environmental and technological conditions. Therefore, it is necessary to create a new pattern of open, green, and shared development for the Chinese industry.

According to some existing literature, the input of research and development (R&D) factors, that is, technological innovation, is believed to have a great impact on China's green development.[2–4] In addition, there are still inconsistencies in regional sustainable development in China and the government's environmental regulations may have a significant impact on the sustainable development of regional cooperation.[5] In terms of the evaluation of the comprehensive development level, factor analysis has proven to be effective in assessing high-quality development for the Chinese economy.[6]

*Author for Correspondence
E-mail: fengmei@ustb.edu.cn

Materials and Methods

Construction of an Evaluation System

Based on the availability of data and the unity of statistical criteria, this study sampled industrial data from 30 provinces in China's east, central, west, and northeast economic regions for research. The study then constructed an evaluation system (see Table 1) based on the PSR model, which contained five primary indicators and 14 secondary indicators, and comprehensively evaluated China's industrial green development level. The data came from *China Statistical Yearbook*, *China Statistical Yearbook on Environment*, *China Energy Statistical Yearbook*, *China High-tech Industry Statistical Yearbook*, and the statistical yearbooks of various provinces. In the empirical process, negative numbers for all reverse index data were forward-processed.

As a commonly-used evaluation model in the field of ecosystem health, the PSR model consists of pressure, state, and response indicators. The pressure indicators express the effects of industrial activities on the environment, such as the disturbance and impact on the ecological environment caused by resource acquisition and the consumption of production means. The state indicators are used to express the state of industrial development, including, among others, the scale of industrial development, the industrial production efficiency, and the investment of industrial enterprises in R&D. The response indicators are used to express what actions industrial enterprises and other social entities can take to mitigate, stop, correct, or prevent the negative impact of industrial production activities on the environment and what measures they can take to remedy ecological environment problems that have been caused by industrial production and are not conducive to social and economic sustainability, including industrial pollution, environmental governance, and the construction of green facilities.

Factor Analysis of Industrial Green Development

Common Factor Extraction

Based on the 2016 industrial data, the empirical method of factor analysis, and the above evaluation system of industrial green development, this study reduced the dimensions of multiple original variables (X_1, X_2...X_n) with strong correlation in the PSR model. Thus, it transformed them into fewer uncorrelated common factors (F_1, F_2...F_m, $m< n$) containing much information about the original variables, to evaluate the level of industrial green development in China's four major economic regions at the time when the *Industrial Green Development Plan (2016–2020)* was initially executed. The original variables were represented by the linear relationship between the common factors.

The factor analysis was performed using the SPSS19.0 software. First, all indicators were examined using the KMO and Bartlett's test (see Table 2), and it resulted in a KMO value of 0.647 > 0.5, a Bartlett's test value of 236.757, and a sig. value of 0.000, each of which meant that the original scalars X_1-X_{14} met the conditions of factor analysis.

Second, the principal component analysis method was used to extract common factors with eigen values higher than 1, which were then rotated by the maximum variance method, and calculated using

Table 1 — Construction of Industrial Green Development Evaluation System

Target layer	Criteria layer	Indicator	Description	Attribute	Symbol
Industrial green development	Industrial development status	Industrial development scale	Industrial value added: Year on Year	+	X_1
			Total average assets of industrial enterprises above designated scale	+	X_2
		Industrial development potential	Industrial enterprises above designated scale: full-time equivalent of R&D personnel	+	X_3
			Industrial enterprises above designated scale: R&D funds/Number of industrial enterprises above designated scale	+	X_4
			Number of valid invention patents of industrial enterprises above designated scale/Number of industrial enterprises above designated scale	+	X_5
			Sales revenue from new products of industrial enterprises above designated scale/Number of industrial enterprises above designated scale	+	X_6
	Ecological environment pressure	Industrial resource utilization	Total industrial water/Industrial value added	-	X_7
			Coal consumption of industrial terminals/Industrial value added	-	X_8
	Social system response	Industrial environment governance	Investment completed for waste water treatment project/Industrial value added	+	X_9
			Investment completed for waste gas treatment project/Industrial value added	+	X_{10}
			Investment completed for solid waste treatment project/Industrial value added	+	X_{11}
			Local financial expenditure on environmental protection/Local financial expenditure	+	X_{12}
		Green facility construction	Green coverage rate in built-up area	+	X_{13}
			Per capita park green space area	+	X_{14}

Table 2 — KMO and Bartlett's Test

Kaiser-Meyer-Olkin test for sampling adequacy		0.647
	Approximate chi-squared	236.757
Bartlett's test for sphericity	df	91
	Sig.	0

regression for their respective scores. The common factors of F_1, F_2, F_3, F_4, and F_5 were extracted for the criteria layer of China's industrial green development level in the PSR model, and they cumulatively contained 79.916% information of the original variables X_1 to X_{14}. The first common factor was heavily loaded on X_4, X_5, and X_6 and reflected the investment in and returns from technological innovation and R&D by regional industrial enterprises. This is an important technological foundation for green and sustainable industrial development and it was labeled as the "industrial development potential factor." The second common factor had a large load on X_9 and X_{10}. It reflected the investment and remediation efforts of various provinces for environmental pollution such as industrial waste water and gas, and it was labeled as the "industrial environment governance factor." The third common factor had a large load on X_2 and it was labeled as the "industrial development scale factor." The fourth common factor had a large load on X_{13} and X_{14} and it was labeled as the "green facilities construction factor." The fifth common factor had a large load on X_7 and it was labeled as the "industrial resource utilization factor." According to the common factors scoring coefficient matrix, the following factor score function was derived, where "i" represented the province:

$$F_{i1}=-0.060X_1+0.122X_2+0.055X_3+0.316X_4+0.321X_5+0.306X_6-0.074X_7+0.087X_8+0.109X_9+0.044X_{10}+0.083X_{11}-0.038X_{12}+0.120X_{13}-0.057X_{14}$$

$$F_{i2}=-0.137X_1+0.097X_2+0.085X_3+0.061X_4+0.048X_5+0.013X_6-0.020X_7-0.255X_8+0.425X_9+0.377X_{10}+0.022X_{11}-0.146X_{12}+0.014X_{13}+0.110X_{14}$$

$$F_{i3}=0.208X_1+0.337X_2-0.417X_3+0.016X_4+0.061X_5-0.042X_6+0.090X_7-0.038X_8-0.185X_9-0.069X_{10}+0.126X_{11}+0.492X_{12}-0.072X_{13}-0.043X_{14}$$

$$F_{i4}=0.394X_1-0.098X_2+0.210X_3-0.044X_4-0.034X_5-0.048X_6+0.048X_7-0.009X_8+0.040X_9-0.009X_{10}+0.023X_{11}+0.211X_{12}+0.302X_{13}+0.447X_{14}$$

$$F_{i5}=-0.335X_1+0.028X_2+0.183X_3-0.034X_4-0.105X_5-0.071X_6+0.469X_7-0.010X_8-0.133X_9+0.089X_{10}-0.540X_{11}-0.011X_{12}+0.005X_{13}+0.131X_{14}$$

Comprehensive Evaluation

To further evaluate and horizontally compare the industrial green development level among different regions in China comprehensively, this study calculated the weighted total score of factors, in which the determination of the weight was critical. A classical way was used to calculate the comprehensive score, i.e. taking the variance contribution rate of each common factor after rotation as the weight. Thus, the comprehensive index and ranking of industrial green development in each region were obtained (Table 3). The specific calculation formula was: $Y=28.389F_1+20.546F_2+12.819F_3+10.302F_4+7.860F_5$.

Result Analysis

The above empirical analysis in this study found that there was still a gap and imbalance in the level of industrial green development among different regions in China in 2016. Judging from the comprehensive scores of the factors, the ten provinces in the eastern region ranked first, the 11 provinces in the western region and six provinces in the central region were in the middle, and the three northeastern provinces came last in terms of the average score among the four major economic regions.

(1) The eastern region had the highest overall level of industrial green development. Specifically, the scores of both the industrial development potential factor and the industrial environment governance factor ranked first, which reflects the obvious industrial technological innovation effect and environmental regulation intensity in the eastern region. In terms of the industrial development scale factor and the green facility construction factor, however, the eastern region did not have significant

Table 3 — Comprehensive Factor Scores of Industrial Green Development in China's Four Major Economic Regions

Regions	Comprehensive factor score	Industrial development status factor score		Ecological environment pressure factor score	Social system response factor score	
		Industrial development scale	Industrial development potential	Industrial resource utilization	Industrial environment governance	Green facility construction
Eastern region	0.226	-0.229	0.226	0.359	0.377	0.093
Western region	-0.030	0.045	0.028	-0.282	-0.249	-0.109
Central region	-0.187	0.138	-0.390	0.246	-0.084	0.137
Northeast region	-0.263	0.322	-0.073	-0.653	-0.173	-0.183

advantages. This might be because eastern China began to shift the industry and accelerate urbanization in the last decade due to the restrictions of production factors such as raw materials and labor and the policy requirements of industrial energy conservation and emission reduction. It entered a high-quality development stage featured by industrial restructuring relying on the industrial technological progress, which weakened the scale effect of green facilities and industrial production.

(2) The northeast region had the lowest comprehensive score for industrial green development, which was in sharp contrast to the eastern region. Its industrial development potential factor and industrial pollution control factor both lagged behind the eastern region, and the industrial green facility factor and industrial resource utilization both ranked last among the four major economic regions. Notably, however, the industrial development scale factor in the northeast region ranked first among the four major economic regions. The northeast region was leading in China before the 1990s not only for its economic development level but also as the most important industrial base. Although it has a solid foundation and a massive layout for the industry, it has gradually fallen behind the eastern coastal region in terms of overall economic development and industrial transformation and upgrading since China's reform and opening up in the 1970s, and the structural contradictions are sharp. Although there is an opportunity to revitalize the old industrial base, there is still much room for improvement in energy-intensive industries with high emission and pollution and in industrial technological innovation. There is an urgent need to realize a system-wide industrial green transformation.

(3) The central and western regions had an intermediate level of industrial green development across the country. Specifically, the central region is at a distinct disadvantage in terms of industrial development potential. Although it has a certain industrial development volume and pays much attention to industrial pollution control, the efforts devoted to industrial R&D are still insufficient compared to other regions. It is only about half of the eastern region, judging from the indicators including the full-time equivalent of R&D personnel, average R&D funds, average number of effective invention patents, and average sales revenue from new products of industrial enterprises above the designated scale. The conversion cycle is long for industrial scientific and technological achievements, and efficiency needs to be improved for industrial technological innovation. The western region had a relatively low level of overall industrial green development. This is because the environmental carrying capacity for its industrial development is lower than that of other regions in China due to the irreversibility of natural resources and because its economy develops slowly, its industrial development volume is small, and its light and heavy industries are out of balance.

Statistical Discussion on Industrial Green Development

As mentioned earlier, China designed an industrial green development plan for 2016–2020. It is still necessary to further observe the industrial green development trend of China's four major economic regions in 2017 and 2018 based on the PSR model after a comprehensive evaluation of the industrial green development in the initial year. As it is difficult to carry out a systematic comprehensive evaluation with the data of some indicators not updated yet, this study still followed the principle of the PSR model, selected X_1, X_5, X_7, X_{12}, and X_{13} of the evaluation system shown in Table 1, and gives a statistical description of the industrial green development in China's various regions from the aspects of industrial development scale, industrial development potential, industrial resource utilization, industrial environment governance, and green facility construction. It is important to note that considering the availability of data, this study replaced indicators of local fiscal expenditure and industrial value addition in the denominators of X_7 and X_{12} with a general budget expenditure of local finance and value addition of the secondary industry, respectively (see Table 4).

(1) Similar to the results of the factor analysis, eastern China, as before, showed strong industrial green development potential and environmental governance capability as well as slow growth in industrial development from 2017 to 2018. However, the indicator of the green coverage rate in the built-up area (X_{13}) from the green facility construction level increased significantly, ranking first in the four major economic regions. This phenomenon is consistent with the above empirical results, which means that the industry of the eastern region has gradually moved from a stage of high-speed growth to a stage of high-quality development. Studies have shown that the

Table 4 — Average Value of Industrial Green Development Indicators in China's Four Major Economic Regions from 2017 to 2018

Year	Region	Industrial value added: year on year (%)	Average number of effective invention patents in industrial enterprises above designated scale (Nos.)	Total industrial water/Value added of secondary industry *100 (%)	Local financial expenditure on environmental protection/General budget expenditure of local finance*100 (%)	Green coverage rate in built-up area (%)
		X_1	X_5	X_7	X_{12}	X_{13}
2017	Eastern region	5.650	4.049	0.288	3.414	41.877
	Western region	6.991	1.481	0.341	2.948	38.331
	Central region	7.967	1.601	0.494	2.826	41.177
	Northeast region	4.200	1.668	0.315	3.145	37.320
2018	Eastern region	5.320	4.538	0.265	3.352	41.920
	Western region	6.927	1.692	0.305	3.067	38.736
	Central region	7.333	1.870	0.469	3.230	41.550
	Northeast region	5.933	1.739	0.313	2.749	37.833

R&D environment is an important transmission route for environmental regulation to promote green technological progress, and the intensity of environmental subsidies in environmental regulation will significantly affect the technological progress effect of environmental regulation policies.[7] In the last two years, eastern China has continuously strengthened its industrial R&D investment and environmental expenditure, far beyond the other three major economic regions. Financial expenditure on environmental protection including environmental subsidies has strongly pushed industrial enterprises in the eastern region to adjust production functions and increase investment in technological factors. This enables enterprises to better improve the efficiency of industrial production through the progress of production technologies, and to reduce the pressure on the ecological environment through enhanced technologies for industrial pollution prevention and environmental control, thus improving the green development level of the whole industry in the eastern region.

(2) Compared to eastern China, various industrial green development indicators in northeastern China, western China, and central China from 2017 to 2018 are still lagging behind, especially in terms of industrial development potential. Human resources and technological resources are the key factors of technological green innovation. In the early 21st century, the eastern region formed a leading industrial economic pattern based on its superior regional position and abundant production factors, attracting a large number of high-tech talent, thus laying a technological foundation for the transformation of the current industrial structure. Correspondingly, however, the loss of talent and technology in the other three major economic regions has widened the gap between them and the economically developed regions in the east, thus slowing down the speed of industrial technological R&D even more when the level of financial expenditure for environmental protection is relatively weak and hindering the process of industrial green development in the region. The Heilongjiang, Jilin, and Liaoning provinces, in particular, as the old industrial bases in northeast China, have been at the bottom of China’s list of provinces and cities in terms of GDP for the past three years. They are facing the dilemma that talent loss leads to economic backwardness, which in turn exacerbates talent loss. This situation is undoubtedly detrimental to the sustainable development of industry in the northeast region.

Conclusion and Prospect

This paper makes a comprehensive evaluation of China’s industrial green development in the last three years based on the PSR model. It was found that the eastern region has an overall leading role and a stronger industrial development potential compared to the central, western, and northeastern regions and that it puts great effort into industrial environment governance and technology R&D. The other three major regions, represented by northeast China, are facing slow progress in industrial green development due to brain drain.

For these reasons, effectively combining the industrial system, technological R&D, and personnel training will become the key to future research on industrial green development. In the follow-up study, we will continue to explore the path of sustainable industrial development with low energy consumption and low pollution, and to fully harness the advantages of human resources, aiming to provide theoretical reference for the green and coordinated industrial development among the regions in China.

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