Journal of World Economic Research
2020; 9(1): 33-40
http://www.sciencepublishinggroup.com/j/jwer
doi: 10.11648/j.jwer.20200901.16
ISSN: 2328-773X (Print); ISSN: 2328-7748 (Online)

Measurement of Regional Industrial Ecological Efficiency in China and an Analysis of Its Influencing Factors

Wu Mingran

School of Management, Nanjing University of Posts and Telecommunications, Nanjing, China

Email address:
wumr1992@163.com

To cite this article:
Wu Mingran. Measurement of Regional Industrial Ecological Efficiency in China and an Analysis of Its Influencing Factors. *Journal of World Economic Research*. Vol. 9, No. 1, 2020, pp. 33-40. doi: 10.11648/j.jwer.20200901.16

Received: December 7, 2019; **Accepted**: December 16, 2019; **Published**: January 17, 2020

Abstract: In recent years, with the rapid advancement of industrialization and urbanization, China's economy has experienced a period of rapid development. However, while China has become the world's second largest economy, it has also become a veritable resource consumer and environmental polluter. So China must need to transform its economic development model and vigorously promote ecological progress. We use interprovincial panel data from 2012 to 2016 to calculate and analyze the industrial ecological efficiency of 31 provinces in China, and then discuss the factors that influence efficiency. The results show that, during the research year, the industrial eco-efficiency of 31 provinces and municipalities in China has been rising steadily in time series but differs significantly in regional cross-sections. Moreover, the eco-efficiency of the eastern region was higher than the central and western regions. Among the influencing factors, the per capita GDP, the proportion of the secondary industry's output value to the regional GDP, and the population density all had a positive impact on industrial eco-efficiency, and the overall industrial eco-efficiency level of the eastern region is higher than the central and western regions. Therefore, the keys to improving regional industrial eco-efficiency are as follows: increasing the income of residents, accelerating the ecological transformation of traditional industries, optimizing the population lay out to alleviate the conflict between people and land, and narrowing the regional development gap.

Keywords: Industrial Eco-efficiency, Economic Development, Industrial Structure, Population Density, Regional Dummy Variable

1. Introduction

In recent years, the negative externalities of industrial economic development have become increasingly serious. Resource depletion and environmental deterioration have become bottlenecks for China’s economic development. Industry is the main source of China’s resource consumption and pollutant emissions. Currently, China’s industrial energy consumption accounts for approximately 71% of the total social energy consumption, and approximately 86% of total smoke (powder) dust emissions come from industrial systems [1]. Therefore, the coordinated development between industry and environmental resources is the key to regional sustainable development. At present, China's industrialization process is at a relatively sensitive and critical period. On the one hand, the development of traditional industries has caused serious environmental pollution and ecological risks, and further more, it has affected social stability and sustainable macro economic development; on the other hand, China's industrial economy will continue to grow for a long time, and its pressure on the ecosystem will undoubtedly continue to increase. It can be predicted that if we continue to follow the traditional industrial development model of "pollution first, treatment later", it will lead to huge ecological risks. If we implement very strict environmental regulations, it may affect the economic growth rate. Therefore, in the next development phase, the government needs to create a balance between economic growth and environmental protection. Efficiency is the core element of an economic system paradigm. It explains how, under realistic conditions with limited resources, decision-makers can control and obtain the most benefits at the lowest possible cost. We constructed the DEA-Tobit model to measure industrial eco-efficiency and make comparisons across provinces and cities in China from 2012 to 2016 for the purpose of determining how to improve industrial eco-efficiently by researching factors that influence industrial eco-efficiency through empirical analysis.

2. Literature Review

The concept of eco-efficiency was first proposed by Schaltegger in 1990 [2] and then was defined as a business development concept by the World Business Council for Sustainable Development in 1992. In academia, there are many definitions of eco-efficiency. We believe that its core idea is to acquire as much economic benefit as possible with the least ecological cost to achieve the coordination of economic benefits and ecological benefits. With the gradual deterioration of resources and the condition of the environment in China, improvements in eco-efficiency are urgently needed for regional development. The level of eco-efficiency not only becomes an important guarantee for the healthy and sustained growth of the regional economy but also becomes a key component in measuring regional competitiveness. With the concept of eco-efficiency entering into the industrial field, academia has carried out a series of fascinating studies focusing on the following three areas: (1) Calculation of the industrial eco-efficiency of the provincial area [3-6]. The results show that the overall level of industrial eco-efficiency in the studied area is not good, and the difference between provinces is very obvious, so there is also a lot of room for improvement. (2) Combining industrial eco-efficiency with scientific and technological innovation, which makes the research results both sustainable and innovative and therefore more comprehensive and reasonable [7-8]. The results show that the improvement of innovation efficiency of regional industrial ecological technology is brought about by scientific and technological progress, and the overall technical efficiency level is not very good in China. However, although the pure technical efficiency of the research area has increased to someextent, China has not formed the scale efficiency of industrial ecological technology innovation. (3) Calculating industrial eco-efficiency based on the enterprise level [9-10]. The researchers have found that the eco-efficiency of industrial enterprises will be affected by environmental impacts, such as government environmental protection investment, corporate R&D investment, etc. Therefore, it is necessary to establish a stable principal-agent relationship between the government, enterprises and the public; to improve the regulatory system of ecological and environmental protection; and to make efforts to increase public participation. The research angles, methods, and viewpoints of the existing literature have made great contributions to this study, but in some respects, the research needs to be further improved. First, most of the existing studies examined only the efficiency differences between various regions but did not further analyze the factors influencing efficiency; that is, the efficiency was not placed in the context of the social development such as regional economic development, industrial structure, and population density, etc. In addition, the results of the existing research also lack applicability to reality. Second, most existing studies only provide the overall efficiency and do not break down its component, which weakens the explanatory power of the research.

Based on the setting of efficiency structure, this paper uses the DEA-Tobit model to measure the industrial eco-efficiency of 31 provinces and cities in China from 2012 to 2016 and further analyzes the possible influencing factors of industrial eco-efficiency. In addition, the paper divides the overall efficiency into two structural efficiencies (pure technical efficiency and scale efficiency) to further clarify the compositional structure of the regional industrial eco-efficiency. Afterwards, we selected some important influencing factors of industrial eco-efficiency in the region and used the constrained dependent variable model (the Tobit model) to analyze it and find more practical recommendations.

3. Calculation and Decomposition of Industrial Eco-efficiency in China

3.1. Industrial Eco-efficiency Measure Model---DEA Model

Data envelopment analysis (DEA) is a cross-disciplinary field of mathematics, operations, and management. It was created and named by Charles, Cooper, and Rhode in 1978 [11] and is considered the ideal method for evaluating the relative validity between different departments (or "units") with multiple inputs and outputs. The most common model in DEA is the BCC model. The basic structure of the BCC model is as follows: Assuming that the industrial eco-efficiency of each DMU (decision making unit) remains the same, we select the DMUs that are comparable to make up a sample set. For each DMU, there are m types of "inputs" and r types of "outputs". Let DMU_j represent the j_{th} production decision unit $(1 \le j \le n)$, x_{ij} represent the amount of the i_{th} input of j_{th} DMU, and $x_{ij} > 0$; v_i represents the weighting coefficient of the i_{th} input variable; u_r represents the weighting coefficient of the r_{th} output variable; and $i = 1,2,\dots,m$; $r = 1,2,\dots,s$; $j = 1,2,\dots,n$; x_{ij} and y_{ij} are the specific values that can be obtained; v_i and u_r are the weights; Let $v = (v_1, v_2, \dots, v_m)^T$, $u = (u_1, u_2, \dots, u_s)^T$, $X_j = (x_{1j}, x_{2j}, \dots, x_{mj})^T$, $Y_j = (y_{1j}, y_{2j}, \dots, y_{rj})^T$. The efficiency evaluation index of DMU is:

$$h_j = \frac{u^T Y_j}{v^T X_j}, j = 1,2,\dots,n \quad (1)$$

To measure the efficiency of DMU_0, we must take the appropriate weight coefficient u_0 、 v_0 to make the maximum value of h_0, which can be reached under the precondition that the efficiency of all DMUs is between 0 and 1. The model can be established as follows:

$$\max h_{0(u,v)} = \frac{u^T Y_0}{v^T X_0}$$

$$\text{s.t. } h_j = \frac{u^T Y_j}{v^T X_j} \le 1, j = 1, 2, \ldots, n \quad (2)$$

and $u > 0, v > 0$

The enveloping form of the model exported by the dual programming is as follows:

$$Min[\delta - \varepsilon(e_m^T s^- + e_r^T s^+)]$$

$$\text{s.t. } \sum_j^n \lambda_j X_j + s^+ = \theta X_0$$

$$\sum_j^n \lambda_j Y_j - s^- = Y_0 \quad (3)$$

$$\sum_j^n \lambda_j = 1$$

$$\lambda_j \ge 0, s^+ \ge 0, s^- \ge 0, j = 1, 2, \ldots, n$$

In this model, the target value θ represents the proportion of the input that DMU_0 needs to reduce. At this time, we can judge whether DMU_0 is valid under the BCC model by the value of θ.

3.2. Variable Definitions and Data Sources

This paper adopts the input variable method and takes the undesired output as the input variable. The main idea is to increase the total industrial output with as few undesired outputs as possible during the development of the industrial economy. This method is very intuitive in handling undesired outputs. Considering that the industrial ecosystem is a complex system with multiple inputs and multiple outputs, the investigation of its efficiency should also fully consider the various related inputs and outputs. Based on previous study experiences on industrial eco-efficiency, considering important conditions, such as consistency of data caliber, the variables selected in this paper are all large-scale statistical data related to industrial ecology. See Table 1 for details.

This article uses 2012 to 2016 as the research years. All basic data are from the 2013–2017 *China Statistical Yearbook* and *China Environmental Statistical Yearbook*. Cooper et al. [12] noted that the number of decision units in the DEA algorithm needs to meet the condition of $n \ge \max\{m \times s, 3(m+s)\}$ to ensure the accuracy of the results, where n represents the number of DMUs; and m and s represents the number of variables for input and output, respectively. This paper meets this condition.

Table 1. *The Indicator System of Industrial Ecological Input and Output.*

Indicator type		Indicator code	Indicator description	Indicator unit
Input indicators	Resource consumption	X1	Industrial energy consumption	10,000 tons of standard coal
		X2	Industrial water consumption	100 million cubic meters
	Environmental pollution	X3	Industrial waste water discharge	10,000 tons
		X4	Industrial chemical oxygen demand emissions	10,000 tons
		X5	Industrial SO_2 emissions	10,000 tons
		X6	Industrial nitrogen oxide emissions	10,000 tons
		X7	Industrial smoke (powder) dust emissions	10,000 tons
		X8	Industrial solid waste emissions	10,000 tons
Output indicators	Industrial economic output	Y1	Industrial added value	100 million yuan

3.3. The Empirical Analysis of Industrial Ecological Efficiency

We used DEAP (version 2.1) software to calculate the industrial eco-efficiency of 31 provinces and cities in China. In this study, the industrial eco-efficiency is represented by the integrated technical efficiency (TE), which is the product of two decomposition variables: pure technical efficiency (PTE) and scale efficiency (SE). The results are shown in Table 2. The provincial area codes used in this table are from the *Announcement on the Internet Domain Name System in China* promulgated by the Ministry of Industry and Information Technology in 2008.

Table 2. *The Calculation Results of China's Regional Industrial Ecological Efficiency between 2012~2016.*

Area	EI	Year 2012	2013	2014	2015	2016	AV	Area	EI	Year 2012	2013	2014	2015	2016	AV
BJ	TE	1	1	1	1	1	1	HB	TE	0.644	0.692	0.699	0.706	0.699	0.688
	SE	1	1	1	1	1	1		SE	0.671	0.706	0.724	0.74	0.769	0.722
	PTE	1	1	1	1	1	1		PTE	0.959	0.98	0.966	0.954	0.909	0.954
TJ	TE	1	1	1	1	1	1	HN	TE	0.656	0.642	0.637	0.655	0.615	0.641
	SE	1	1	1	1	1	1		SE	0.693	0.657	0.663	0.674	0.666	0.671
	PTE	1	1	1	1	1	1		PTE	0.946	0.977	0.96	0.972	0.923	0.956
HE	TE	0.459	0.5	0.459	0.48	0.685	0.517	GD	TE	1	1	0.99	1	0.951	0.988
	SE	0.616	0.568	0.537	0.537	0.751	0.602		SE	1	1	1	1	1	1
	PTE	0.746	0.879	0.854	0.893	0.913	0.857		PTE	1	1	0.99	1	0.951	0.988

Area	EI	Year					AV	Area	EI	Year					AV
		2012	2013	2014	2015	2016				2012	2013	2014	2015	2016	
	TE	0.46	0.473	0.416	0.386	0.422	0.431		TE	0.385	0.408	0.387	0.418	0.68	0.456
SX	SE	0.536	0.504	0.451	0.41	0.434	0.467	GX	SE	0.393	0.413	0.401	0.429	0.687	0.465
	PTE	0.859	0.937	0.922	0.942	0.971	0.926		PTE	0.979	0.987	0.967	0.974	0.99	0.979
	TE	0.556	0.62	0.57	0.55	0.868	0.633		TE	0.376	0.351	0.296	0.28	0.816	0.424
IM	SE	0.625	0.64	0.595	0.567	0.87	0.659	HI	SE	0.782	1	1	0.419	1	0.84
	PTE	0.889	0.968	0.958	0.97	0.998	0.957		PTE	0.481	0.351	0.296	0.669	0.816	0.523
	TE	0.758	0.775	0.745	0.67	0.639	0.717		TE	0.523	0.544	0.544	0.603	0.622	0.567
LN	SE	0.819	0.805	0.795	0.697	0.687	0.761	CQ	SE	0.525	0.544	0.546	0.606	0.638	0.572
	PTE	0.926	0.962	0.936	0.961	0.931	0.943		PTE	0.996	1	0.996	0.995	0.975	0.992
	TE	0.875	0.951	0.963	0.977	0.856	0.924		TE	0.64	0.615	0.607	0.606	0.625	0.619
JL	SE	0.878	0.956	0.969	0.985	0.857	0.929	SC	SE	0.658	0.62	0.613	0.629	0.683	0.641
	PTE	0.997	0.995	0.993	0.992	0.999	0.995		PTE	0.974	0.991	0.991	0.964	0.914	0.967
	TE	0.471	0.462	0.46	0.437	0.536	0.473		TE	0.205	0.228	0.23	0.246	0.552	0.292
HL	SE	0.478	0.466	0.464	0.439	0.537	0.477	GZ	SE	0.215	0.232	0.235	0.253	0.555	0.298
	PTE	0.984	0.992	0.993	0.995	0.998	0.992		PTE	0.954	0.984	0.981	0.971	0.996	0.977
	TE	1	1	1	1	1	1		TE	0.221	0.225	0.21	0.207	0.593	0.291
SH	SE	1	1	1	1	1	1	YN	SE	0.226	0.23	0.219	0.221	0.596	0.298
	PTE	1	1	1	1	1	1		PTE	0.976	0.98	0.961	0.935	0.995	0.969
	TE	0.974	1	1	1	1	0.995		TE	0.121	0.141	0.129	0.139	0.392	0.184
JS	SE	1	1	1	1	1	1	XZ	SE	1	1	1	1	1	1
	PTE	0.974	1	1	1	1	0.995		PTE	0.121	0.141	0.129	0.139	0.392	0.184
	TE	0.905	0.879	0.83	0.82	0.802	0.847		TE	0.462	0.468	0.442	0.446	0.637	0.491
ZJ	SE	1	1	1	0.972	0.955	0.985	SN	SE	0.479	0.477	0.455	0.456	0.647	0.503
	PTE	0.905	0.879	0.83	0.844	0.839	0.859		PTE	0.965	0.98	0.971	0.978	0.986	0.976
	TE	0.673	0.649	0.621	0.65	0.657	0.65		TE	0.353	0.434	0.405	0.443	0.778	0.483
AH	SE	0.71	0.675	0.662	0.684	0.717	0.69	GS	SE	0.356	0.442	0.412	0.452	0.787	0.49
	PTE	0.949	0.962	0.937	0.952	0.916	0.943		PTE	0.991	0.982	0.982	0.979	0.988	0.984
	TE	0.703	0.739	0.748	0.761	0.759	0.742		TE	0.257	0.301	0.29	0.308	0.592	0.35
FJ	SE	0.711	0.742	0.752	0.763	0.772	0.748	QH	SE	0.307	0.356	0.349	0.399	0.624	0.407
	PTE	0.99	0.996	0.995	0.997	0.983	0.992		PTE	0.838	0.846	0.831	0.77	0.949	0.847
	TE	0.733	0.794	0.808	0.854	0.715	0.781		TE	0.196	0.268	0.273	0.298	0.605	0.328
JX	SE	0.748	0.802	0.821	0.866	0.76	0.799	NX	SE	0.206	0.286	0.294	0.325	0.624	0.347
	PTE	0.98	0.99	0.984	0.986	0.941	0.976		PTE	0.95	0.937	0.929	0.915	0.97	0.94
	TE	0.932	0.957	0.929	0.949	0.932	0.94		TE	0.266	0.28	0.266	0.286	0.651	0.35
SD	SE	1	1	1	1	1	1	XJ	SE	0.277	0.286	0.275	0.291	0.657	0.357
	PTE	0.932	0.957	0.929	0.949	0.932	0.94		PTE	0.961	0.981	0.967	0.98	0.991	0.976
	TE	0.59	0.581	0.588	0.652	0.584	0.599		TE	0.593	0.612	0.598	0.607	0.718	0.626
HA	SE	0.647	0.609	0.628	0.684	0.664	0.646	Average	SE	0.663	0.678	0.673	0.661	0.772	0.689
	PTE	0.912	0.955	0.936	0.954	0.881	0.928		PTE	0.908	0.922	0.909	0.924	0.937	0.92

Note: EI—Efficiency index; AV—Average value.

As seen from Table 2, the average industrial eco-efficiency of 31 provinces in China between 2012 and 2016 was 0.626, the PTE was 0.92, and the SE was 0.689. The efficiency structure showed the situation of PTE>SE>TE. In the regional performance, our findings are consistent with those in the existing literature: the eastern region is higher than the central region, and the central region is higher than the western region[1]. Among them, the eco-efficiency values of only three municipalities, BJ, TJ, and SH, were on the frontier of efficiency during the whole research year. In addition, the eco-efficiency values of the four provinces of GD (0.988), JL (0.924), JS (0.995), and SD (0.94) are all greater than 0.9. Although these four provinces are not effective units, they all had good industrial eco-efficiency values. It is worth noting that the abovementioned provinces with high industrial eco-efficiency values are all located in the eastern region. Therefore, there exists a huge difference in the levels of industrial eco-efficiency between different regions of China.

It is worth noting that the industrial eco-efficiency values of 15 provinces, including HA (0.599), CQ (0.567), HE (0.517), SN (0.491), GS (0.483), HL (0.473), GX (0.456), SX (0.431), HA (0.424), QH (0.35), XJ (0.35), NX (0.328), GZ (0.292), YN (0.291), and XZ (0.184) are below 0.6, which is a low level. The overwhelming majority of these provinces belong to the central and western regions. Their modernization processes have made relatively little progress, and the level of industrial development is relatively low. Their scientific and technological strength and environmental protection inputs are also far from the levels of the developed eastern

[1]The specific divisions in each region of this paper are: the eastern region, which includes 11 provinces of LN (Liaoning), HE (Hebei), BJ (Beijing), TJ (Tianjin), SD (Shandong), JS (Jiangsu), ZJ (Zhejiang), SH (Shanghai), FJ (Fujian), GD (Guangdong), and HA (Hainan); the central region, which includes ten provinces of HL (Heilongjiang), JL (Jilin), IM (Inner Mongolia), SX (Shanxi), HA (Henan), HB (Hubei), JX (Jiangxi), AH (Anhui), GX (Guangxi) and HN (Hunan); and the western region, which includes 10 provinces of SN (Shaanxi), GS (Gansu), QH (Qinghai), NX (Ningxia), XJ (Xinjiang), SC (Sichuan), CQ (Chongqing), YN (Yunnan), GZ (Guizhou) and XZ (Tibet).

regions. There are many reasons that led to these regions paying a higher ecological price for industrial development. In addition, there is another factor that cannot be overlooked: Due to the delayed progress of economic development, the central and western regions have a stronger desire for economic development than does the eastern region, which has led to relatively weak environmental regulations and ecological protection initiatives. This situation has long caused the transfer of polluting enterprises from the eastern region to the central and western regions, resulting in repeated pollution and further damage to the ecology in the transferred areas. In recent years, the phenomenon of pollution transfer caused by interregional industrial transfer has become more and more common. Therefore, when the Chinese government faces the transfer of high-polluting enterprises across administrative regions, it is imperative to formulate and implement integrated regional environmental protection regulations and to promote the establishment of cross-regional ecological compensation mechanisms to implement the joint prevention and treatment of environmental pollution across different regions.

4. Econometric Analysis of the Influencing Factors of Industrial Eco-efficiency

4.1. The Analysis Model of the Influencing Factors of Industrial Eco-efficiency—Tobit Model

After using the DEA model to calculate the industrial eco-efficiency values of various regions in China, we further analyze the influencing factors. Based on the understanding of the concept of industrial eco-efficiency and the reference to previous literature, we believe that the regional industrial eco-efficiency may be affected by factors such as the economy, industry, population, and regional geographical location. At the same time, we predict the mechanism of action of various influencing factors (see Table 3).

Table 3. *Variable description.*

Variable name	Variable code	Variable definitions and units	Prediction
Economic development	Ln (GP)	GDP per capital (yuan per person)	Positive
	GR	Regional GDP as a proportion of national GDP (%)	Positive
Industrial structure	PI	The proportion of the secondary industry's output value to the regional GDP (%)	Unknown
Population density	Ln(PD)	The ratio of population amount to area (people per km^2)	Unknown
Regional dummy variable	EAST	If the area is in the east, EAST=1; otherwise EAST=0	Positive

4.2. The Establishment of a Regression Model

To further analyze the influencing factors of regional industrial eco-efficiency, we used the comprehensive TE values in Table 2 as the interpreted variables and selected a number of indicators that may affect industrial eco-efficiency (see Table 3) and comprehensively analyzed the role of various factors that influence industrial eco-efficiency in China. Since these variables are time series data, the stability of the data is critical. In this paper, we first took a logarithmic treatment of the two indicators of GP and PD before the regression. The first purpose was to eliminate the huge differences in numerical values with other variables by smoothing the index and reducing or eliminating the heteroscedasticity; the second purpose was that the coefficients after regression would have the concept of elasticity and express the rate of change.

$$TE_{it} = \beta_0 + \beta_1 GR_{it} + \beta_2 \ln(GP_{it}) + \beta_3 PI_{it} + \beta_4 \ln(PD_{it}) + \beta_5 EAST_{it} + \varepsilon_{it}$$

In the expression, TE_{it} represents the industrial eco-efficiency value; the right side of the equation contains the influencing factors of the industrial eco-efficiency of the provinces, where $\beta_i (i = 0,1,2,3,4,5)$ represents the undetermined coefficient, ε_{it} is the random error term, i is the regional number, and t is the year.

4.3. Result Analysis

Through Eviews7.2 software, a maximum likelihood estimation program is used to process the Tobit model and makes the regression to the above panel data. The results are shown in Table 4.

Table 4. *The regression results of the Tobit model.*

Variable name	Variable code	Coefficient value	Standard error	Z value	P value
Economic development	ln(GP)	0.347976	0.03276	10.62207	0
	GR	2.893855	0.568108	5.093844	0
Industrial structure	PI	0.029203	0.14014	0.208383	0.0349
Population density	ln(PD)	0.053376	0.009246	5.773173	0
Regional dummy variable	EAST	0.0642	0.031437	-2.04224	0.0411
Constant term	C	-3.20371	0.348233	-9.19989	0

(1) Economic development level has a positive impact on regional industrial eco-efficiency. The estimation result of the Tobit model shows that the relationship between the regional industrial eco-efficiency and two indicators of ln(GP) and GR are positive, and the p value is 0, indicating that the difference is extremely significant. Per capita GDP represents the regional per capita income, and the proportion of regional GDP to national GDP represents the strength of the regional economy. The result of this model may be because economically favorable regions mostly have high levels of modernization and industrialization. A relatively complete industrial system and large environment protection investments have enabled the region to exhibit good industrial ecological performance.

(2) Industrial structure has a positive impact on regional industrial eco-efficiency. The coefficient value of the industrial structure is 0.0292. That means that when the proportion of the secondary industry's output value to the regional GDP increases by 1 percent, the regional industrial eco-efficiency increases by 0.0292 percent. In addition, the P value is 0.035, passing the 5% level significance test. The reason may be that if the proportion is higher, the status of the industry is more prominent and the government pays a higher degree of attention to industrial development and is further willing to invest more in its ecological development, thus improving the regional industrial eco-efficiency. It should be noted that as the most important industrial type in China's national economy, the secondary industry has the status that other industries cannot replace. Therefore, regardless of whether its proportion in the industrial structure is large or small, each region should pay great attention to the dominant position of the secondary industry. Especially in the current situation of resource shortage, excessive development, and increased pollution, it is of great importance to ensure the healthy and stable development of the secondary industrial economy.

(3) Population density has a positive effect on regional industrial eco-efficiency. The coefficient value is 0.0534, which means that when the population density increases by 1 percent, the regional industrial eco-efficiency increases by 0.0534 percent. In addition, the p value is 0, indicating that the difference is extremely significant. There may be two reasons for this phenomenon: First, the regions with higher population density often have higher economic development and modernization level, and these regions mostly perform well in the development of industrial ecology performance. Second, with people's tolerance to industrial pollution decreasing in recent years, regions with higher population density always have stricter demands on environmental quality. In addition, people's increasing awareness of environmental protection in recent years will also have a regulatory effect on industrial companies. For industrial companies with high pollution and high consumption, people tend to litigate to safeguard their rights and interests, forcing companies to either make changes or leave.

(4) Regional dummy variables have a positive effect on regional industrial eco-efficiency. The coefficient value is 0.0642 and the p value is 0.0411, passing the 5% level significance test. This shows that the overall industrial eco-efficiency level of the eastern region of China is better than that of the central and western regions, which confirms the previous judgment. It is worth noting that the central and western regions with low industrial eco-efficiency levels have a stronger and more urgent desire for economic development than the eastern region. Therefore, the government should pay attention to the organic combination of the regional industrial economic development and ecological civilization construction. The central and western regions cannot repeat the mistake of "pollution first, treatment later" in economically developed regions. In the future, the central and western regions should according to their own conditions and advantages, put the development of a green economy on the agenda, strengthen the supervision of pollution emissions, and increase financial investment to promote the upgrade of traditional industries. In addition, they can be more scientific and rational when undertaking the industrial transfer of the eastern region and strictly control the entry of industries with high energy consumption and pollution. The central government should make efforts to support regions with poor performance in industrial eco-efficiency to further mitigate regional disparities and achieve the strategic goal of regionally coordinated development of industrial eco-efficiency.

5. Conclusions and Suggestions

We first used the DEA model to calculate the industrial eco-efficiency of various provinces and cities between 2012 and 2016 in China. The results show that during the study years, the average industrial eco-efficiency level for all provinces and cities was 0.626, and the efficiency performed relatively consistently in the time series but showed a significant difference in the regional comparison. The eastern provinces and cities of BJ, TJ, SH, GD, JS, and SD are the places with the highest industrial eco-efficiency in China. The industrial eco-efficiency of the central and western provinces, such as HA, CQ, HB, and SN, are relatively low. Most of the industrial components in these low-level regions are traditional manufacturing industries with high energy consumption and high pollution. They are mostly in the stage of rapid economic growth. It is foreseeable that, as the economy develops further, the industrial eco-efficiency in these areas will further decline.

Next, we used the Tobit model to conduct a regression analysis for some factors affecting industrial eco-efficiency. The results show that economic development, industrial structure, population density, and regional dummy variables all have a positive impact on regional industrial eco-efficiency. Therefore, measures for improving the industrial eco-efficiency and promoting balanced development between regions should be based on the above analysis and mainly in the following aspects:

(1) Vigorously promote the ecological transformation of Chinese industrial enterprises. The transformation of production modes of industrial enterprises is crucial to the construction and development of industrial ecosystems. Therefore, on the one hand, the government needs to adopt scientific measures to strictly control the capacity of regional industrial enterprises to discharge pollutants and to promote the cleanliness of production and consumption of industrial enterprises through the establishment of the recycling industry chain and to increase the efficiency of the use of energy resources and to accelerate the sharing of technological industrial symbiosis to strengthen the coupling of economic benefits and ecological benefits of different industrial enterprises; on the other hand, it is necessary to speed up the transformation and upgrading of traditional industries and to update the production methods through R&D and the introduction of high-tech and applicable technologies to accelerate the deep integration of science and technology with industrialization. In addition, it is essential to strictly control the scale and capacity expansion of traditional enterprises with high energy consumption and pollution. The central and local governments need to take into account the different development statuses and ecological needs of different regions, properly strengthen the constraints of ecological indicators, and actively eliminate those manufacturing and production processes and poor production capacities that waste resources and create environmental pollution.

(2) Rationally plan environmental regulation in different regions and narrow the development gap in regional ecological levels. According to the above analysis, the reason that the eastern coastal area could achieve good results in industrial ecologicalization is closely related to its high level of economic development, reasonable industrial structure, and high investment in environmental protection. In contrast, the regions with relatively low economic levels in the central and western regions mostly have insufficient ecological development levels. In addition, the central and western regions have extremely urgent demands and aspirations for economic development and accordingly have relatively low enthusiasm for environmental protection. Recently, more and more high-polluting industrial enterprises in the eastern region have chosen to transfer to the central and western regions in order to avoid stricter environmental regulations in the eastern region [13]. In this regard, the central government should focus on perfecting the testing and evaluation mechanisms for regional environmental regulations in China. In particular, we must strengthen the implementation of ecological regulation in areas with low levels of economic development to avoid excessive differentiation in the intensity of environmental regulations in different provinces. Moreover, we should make efforts to increase the financial incentives for polluting industries to encourage them to reduce the damage to the environment through equipment upgrading and technological progress rather than circumvent the high environmental costs simply by industry transfer.

(3) Improve the quality of urbanization and optimize population distribution. From the above study results, we know that the regional population density is closely related to industrial eco-efficiency. Theoretically speaking, when the regional population density reaches optimal levels, the resident living standards and the ecological environment will be ideal. If they are lower than the optimal level, economic development will lack support. If the optimal level is exceeded, the ecological carrying capacity will be under pressure. Therefore, the government should implement differentiated urbanization development strategies and efficient economic development models based on industrial structure characteristics and market development conditions in different regions, vigorously promote the development of environmental protection industries, and build ecologically livable cities to promote regional ecological environment. In the future, the development of urbanization needs to take some factors into consideration, such as high quality of life, resource conservation, environmental friendliness, etc. We should avoid blindly pursuing rapid development and steadily improve the quality of urbanization under the premise of optimizing population density and layout.

Acknowledgements

The authors are grateful for the financial support provided by the National Natural Science Foundation of China (Grant No. 41401634), the Fundamental Research Funds from the

Central Universities (Grant No. 2016B31914) and the Chinese Scholarship Council.

References

[1] Stefan Schaltegger, Andreas Sturm. Ökologische Ratio-naliät//Die Unternehmung Nr4/90, 1990: 273-290.

[2] Liu X M, Meng X R, Wang K L. Measurement and Evaluation of Urban Industrial Ecological Efficiency: Empirical Evidence from Anhui Province [J]. East China Economic Management, 2016, (8): 29-34.

[3] Zhang W M, Fang Q M, Liu T. Eco-efficiency evaluation of urban industries: taking Hunan Province for example [J]. Urban Problems, 2015, (3): 62-66+104.

[4] Wu M R, Ma J. Measurement on Regional Ecological Efficiency in China and Analysis on Its Influencing Factors: Based on DEA-Tobit Two-stage Method [J]. Technology Economics, 2016, (3): 75-80+122.

[5] Dai Z M, Zeng Y H, Guo L. Study of the Industrial Eco-efficiency with the Panel Data in East China——Based on the Super Efficiency DEA Model [J]. Soft Science, 2016, (7): 35-39.

[6] Han J P, Wen A L, Yan J. A Research of China's Industrial Eco-innovation Efficiency Based on DEA Model [J]. Ecological Economy, 2016, (5): 102-105.

[7] You D M, Huang X Z. Evaluation on Provincial Industrial Eco-Technology Innovation Efficiencyin Yangtze River Economic Zone [J]. Economic Geography, 2016, (9): 128-134.

[8] Gao W. Research on Industrial Enterprises' Co-Effi ciency and Pollution Control in China [J]. Ecological Economy, 2017, (1): 21-27.

[9] Zhao S, Liu H. Evaluation of Industrial Enterprise's Co-Efficiency Based on Three-Stage DEA Model in China [J]. Ecological Economy, 2016, (11): 88-91+102.

[10] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units [J]. European Journal of Operation Research, 1978 (2): 429-444.

[11] Copper, W. W., Li, S., Seiford, L. M., et al. Sensitivity and stability analysis in DEA: Some recent development [J]. Journal of Productivity Analysis, 2001, 15 (3): 217-246.

[12] Fu S X. Study on the Industrial Regional Distribution of Ecological Civilization [M]. Beijing: Encyclopedia of China Publishing House, 2016.

[13] Pan X X, He Y Q. A Study on Evaluation of Industrial Eco-efficiency and Its Influencing Factors—Based on Provincial Panel Data in Central and East China [J]. East China Economic Management, 2014, 28 (3): 33-38.

Biography

Wu Mingran (1992-) is a native of Hefei of Anhui and a doctoral student of business administration at Hohai University. His main research interests are environmental and resource economics.