Research on the Efficiency of Green Innovation in Cities in the Yellow River Basin

Wangmin Lu1,a

1International Business School, Shaanxi Normal University, Xi’an, Shaanxi Province, China
aemail: luwangmin1996@snnu.edu.cn

Abstract. This paper constructs an evaluation system of urban green innovation efficiency, and based on SBM-Undesirable model, calculates the green innovation efficiency of 56 cities in the Yellow River basin from 2013 to 2017, with a view to evaluating the green innovation efficiency of cities in the Yellow River basin. The study finds that, between 2013 and 2017, the overall green innovation efficiency of cities in the Yellow River basin is at a low level, with a mean value of only 0.535. The inner differences of green innovation efficiency between cities in the Yellow River basin are large. At the same time, cities in the lower reaches of the Yellow River basin have the highest average green innovation efficiency, followed by cities in the upper reaches. Cities in the middle reaches of the Yellow River basin are relatively low, so there is still much room for improvement.

1. Introduction
In September 2019, at the Symposium on Ecological Protection and High-quality Development of the Yellow River Basin, General Secretary Xi Jinping made a major deployment to strengthen the governance and protection of the Yellow River and promote the high-quality development of the Yellow River Basin. The Yellow River flows through 9 provinces (regions) including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong. The Yellow River Basin is mostly dominated by traditional resource-intensive industries, and the industrial structure shows a clear tendency of heavy chemical industry. The leading industries have high energy consumption, high water consumption, and large pollution problems. The development of high-tech and strategic emerging industries in the Yellow River Basin is lagging behind, and the quality of industrial development is not high, facing the severe challenge of ineffective conversion of new and old kinetic energy. Green innovation is an organic combination of the two development concepts of green and innovation, taking into account economic and environmental benefits, and is the backbone of high-quality economic development. In terms of empirical research, the current research on the Yellow River Basin has achieved certain results[1-2], but there are few studies on the Yellow River Basin from the perspective of green innovation efficiency, far less than the Yangtze River Basin. Therefore, this paper constructs an urban green innovation efficiency evaluation system. Based on the SBM-Undesirable model, it measures the green innovation efficiency of 56 cities in the Yellow River Basin from 2013 to 2017, in order to evaluate the green innovation efficiency of cities in the Yellow River Basin, so as to serve the Yellow River Basin. It is of great significance to effectively evaluate and improve the efficiency of green innovation in the Yellow River Basin for promoting ecological protection and high-quality development of the Yellow River Basin.
2. Materials and Methods

2.1. Data sources

This study takes 56 cities in the Yellow River Basin from 2013 to 2017 as the research objects. The data comes from the 2014-2018 China City Statistical Yearbook, the statistical yearbooks of various provinces and cities, and the national economic and social development statistical bulletins of relevant cities. Some missing values are supplemented by linear interpolation.

In accordance with the relevant regulations of the Yellow River Conservancy Commission of the Ministry of Water Resources, this paper divides the Yellow River basin into three regions: upper, middle, and lower reaches according to the provincial administrative unit based on the geographical location of 56 cities.

| Upper reaches | Middle reaches | Lower reaches |
|---------------|----------------|---------------|
| Xining, Baiyin, Wuwei, Qingyang, Dingxi, Lanzhou, Longnan, Yinchuan, Shizuishan, Guyuan, Zhongwei, Hohhot, Baotou, Wuhai, Ordos, Bayannur | Xi’an, Xianyang, Tongchuan, Yan’an, Yulin, Baoji, Weinan, Shangluo, Taiyuan, Datong, Shuozhou, Xinzhou, Yangquan, Luliang, Jinzhong, Changzhi, Jincheng, Linfen, Yuncheng | Zhengzhou, Kaifeng, Luoyang, Sanmenxia, Anyang, Xinxiang, Shangqiu, Puyang, Hebi, Jiaozuo, Jinan, Zibo, Dongying, Jining, Tai’an, Dezhou, Liaocheng, Binzhou, Heze, Qingdao, Weifang |

2.2. Indicators selection

In this paper, the connotation of green innovation efficiency is taken into account, and the indicators that have been studied on green innovation efficiency and the availability of data are referred to. The selected indicators are as follows:

| Input indicator 1 | Science and technology manpower input | Number of people engaged in scientific research and technical services |
|-------------------|--------------------------------------|-------------------------------------------------------------------|
| Input indicator 2 | Green manpower input                 | Number of people engaged in water conservancy, environment, and public facilities management |
| Input indicator 3 | Financial investment                  | Science and technology expenditure in local fiscal expenditure |
| Output indicator 1 | Expected output                       | GDP                                                               |
| Output indicator 2 | Undesired output                     | Industrial wastewater discharge                                    |
| Output indicator 3 | Undesired output                     | Industrial sulfur dioxide emissions                                |

2.3. The research method

2.3.1. SBM-Undesirable model.

Data Envelopment Analysis (DEA) is the main measurement method of green innovation efficiency[3]. This method does not need to set up the function form in advance, the operation is simple, and the evaluation result is relatively objective. However, the traditional DEA model has shortcomings. In order to overcome the shortcomings of the existing traditional DEA model, Tone proposed a new type of DEA-SBM model, which puts the slack variable directly into the objective function, which not only solves the problem of input It also solves the problem of efficiency evaluation in the presence of undesired output[4].

The linear programming form of the SBM model is as follows:
In the formula, \( s \) represents the amount of slack. \( s^-, s^g, s^b \) represents excessive investment, insufficient expected output, and excessive undesired output. \( \lambda \) represents the weight of each variable. The numerator and denominator of the objective function \( \rho^* \) represent the actual investment of the decision-making unit, output, and the average distance to the production frontier. If \( s^- = 0, s^g = 0, s^b = 0 \), the decision-making unit is effective.

3. Results & Discussion

According to the above method, using DEA Solver Pro5.0 software to select the undesired output model to measure the green innovation efficiency of 56 cities in the Yellow River Basin.

Figure 1. Specific green innovation efficiency values of cities in the Yellow River Basin

It can be intuitively seen from Figure 1 that the green innovation efficiency of cities in the Yellow River Basin varies greatly internally. For example, from the results of green innovation efficiency of cities, the green innovation efficiency value of Xi’an and Qingdao are all 1, reaching the forefront of efficiency, while the green innovation efficiency value of Jinchong reaches 0.243. The reason lies in the fact that the governments of Qingdao and Xi’an strongly advocate innovation-driven development and follow a series of plans and incentive policies related to the promotion of scientific and technological innovation. Therefore, the expected output of Qingdao and Xi’an, namely the number of patent applications, ranks top in these two regions.
Table 3. Types of Green Innovation Efficiency of Cities in the Yellow River Basin

| Types of green innovation efficiency | Cities                                               |
|-------------------------------------|-----------------------------------------------------|
| high efficiency (0.8-1)             | Qingyang, Xi’an, Jinan, Qingdao, Dongying, Liaocheng, Binzhou, Bayannur, Jining, Ordos, Xianyang, Tai’an, Baotou, Weifang |
| medium efficiency (0.1-0.5)         | Yangquan, Hohhot, Zibo, Puyang, Shangqiu, Heze, Jiaozuo, Yan’an, Shangluo, Baoji, Zhengzhou, Baiyin |
| low efficiency (0.1-0.5)            | Anyang, Shuozhou, Xining, Xinxiang, Dezhou, Shizuishan, Luoyang, Wuwei, Sanmenxia, Kaifeng, Hebi, Lvliang, Tongchuan, Lanzhou, Datong, Yuncheng, Linfen, Jincheng, Yulin, Dingxi, Yinchuan, Taiyuan, Longnan, Changzhi, Jinzhong, Weinan, Zhongwei, Xinzhou, Wuhai, Guyuan |

In order to compare the differences of green innovation efficiency in cities in the Yellow River Basin, the efficiency values were grouped into three types: high, medium and low. The efficiency values in the high-efficiency areas were between 0.8-1. In areas with high efficiency, the efficiency value is between 0.5-0.8. In low and medium efficiency areas, the efficiency value is between 0.1 and 0.5. As shown in Table 3, there are 14 cities with high green innovation efficiency, most of which belong to the upstream and downstream basins, with Shandong province accounting for the largest proportion, because it is located in the eastern region with a higher technical level and a more complete industrial system compared with the western region. There are 12 cities with high green innovation efficiency, and most of them are upstream and downstream. Low efficiency of green innovation city accounted for 54%, mostly in the upstream and middle cities, including 13 middle city, Shanxi Province city accounted for the largest, which is closely connected with economic structure of Shanxi Province, Shanxi Province is the resource-rich province, because of the path dependence, environmental pollution, resource consumption more serious, and insufficient innovation power, so the bottom of the green innovation efficiency in the Yellow River city.
As is shown in Table 4, the overall green innovation efficiency of cities in the Yellow River Basin is at a low level, with an average green innovation efficiency of 0.535 from 2013 to 2017. From 2013 to 2017, the efficiency of green innovation in cities in the lower reaches of the Yellow River basin showed a slow rise on the whole. However, the efficiency of urban green innovation in the upper and middle reaches of the Yellow River basin presents an unstable state, with two or three times of efficiency drops during 2013-2017. The highest average green innovation efficiency of cities in the lower reaches of the Yellow River basin was 0.671, which was also higher than the overall average of 0.535 in the five years of the Yellow River Basin. The urban green innovation efficiency in the upper reaches of the Yellow River basin came second, with an average of 0.484. The green innovation efficiency of cities in the middle reaches of the Yellow River basin is lower than that in the upper and lower reaches, with an average of 0.427. The reason is that the middle reaches of the Yellow River include Shaanxi and Shanxi. Shanxi is a big coal province, and its economic development has been relying on coal resources and other natural resources for a long time, which inevitably leads to serious environmental pollution. Shaanxi, as an old industrial base, has a single industrial structure and is facing challenges in terms of resources and environment. However, the upper reaches of the Yellow River and the western regions such as Ningxia, Inner Mongolia and Qinghai have a weak innovation foundation, with unsatisfactory innovation output and low patent applications. At the same time, it also shows that the innovation ability and green development ability of the middle and upper reaches of the Yellow River basin are generally poor, the extensive characteristics of economic development are obvious, and the improvement of innovation ability is accompanied by more environmental pollution and energy consumption, which is unsustainable in the long run.

4. Conclusions

Based on SBM-Undesirable model, the green innovation efficiency of 56 cities in the Yellow River basin was measured from 2013 to 2017, and the following conclusions were obtained:
The green innovation efficiency of the whole cities in the Yellow River basin is at a low level. The average green innovation efficiency of cities in the lower reaches of the Yellow River Basin is the highest, followed by those in the upper reaches, while the efficiency of green innovation in cities in the middle reaches is low, so there is still much room for improvement.

The green innovation efficiency of cities in the Yellow River Basin varies greatly internally, and the green innovation efficiency value of some cities is 1, reaching the forefront of efficiency. And the efficiency of green innovation in some cities is not effective.

According to the average value of green innovation efficiency of each city from 2013 to 2017, efficiency values are grouped into three types according to high, medium and low. Cities with high green innovation efficiency account for 25%, most of which belong to upstream and downstream basins. Cities with high green innovation efficiency accounted for 21%, with the upstream and downstream cities in the majority. Cities with low and medium green innovation efficiency accounted for the largest proportion, mainly in the upper and middle reaches.

Based on the above conclusions, this paper draws the following inspirations: in the process of development and innovation, attention should be paid to the quality of innovation output and environmental pollution to improve the efficiency of green innovation. Cities in the upper, middle and lower reaches of the Yellow River should take green as the development concept and innovation as the driving force to improve the efficiency of green innovation in cities in the Yellow River Basin. It is imperative to realize the green and sustainable development of cities in the Yellow River Basin.

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