Evaluation of green innovation ability of regional high-tech industries—Taking Hebei province as an example

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Abstract. Green innovation is one of the effective ways to realize national economic growth, environmental protection and social harmony. This paper takes the green innovation of high-tech industry in Hebei Province as the empirical research object, and constructs the evaluation index system from three aspects: green innovation input capacity, green innovation output capacity and green innovation environment capacity. Taking 31 provinces/cities/autonomous regions across the country as a comparative sample, the factor analysis method is used to evaluate the green innovation capability of Hebei’s high-tech industry. The overall green innovation ability of high-tech industry in Hebei Province is relatively low. The comprehensive score of green innovation ability, countermeasures and suggestions are put forward to realize the green and innovation integration of high-tech industry in Hebei Province.

1. Introduction
As the main source of power leading my country’s economy towards high-quality development, high-tech industries not only possess advanced technology, but also lead the development of other industries. Green innovation is an effective driving force for the development way for my country to achieve high-quality economic development and enhance international competitiveness. The Ministry of Industry and Information Technology issued the “Industrial Green Development Plan(2016-2020)”, which pointed out the establishment and improvement of a long-term mechanism for industrial green development, improving green international competitiveness, taking an efficient, clean, low-carbon, and circular green development path, and promoting industrial civilization and ecology. Civilization and harmony are in harmony and harmony between man and nature is realized. This requires economic development and ecological civilization construction to move forward side by side in the development of high-tech industries as the source of development. Under the new development situation, with the coordinated development of Beijing-Tianjin-Hebei and the establishment of the Xiongan New District, Hebei Province has great potential for the development of green innovation in high-tech industries. How can Hebei Province break through the original innovation model, rely on forces at all level to explore new models for the development of green innovation in high-tech industries, and integrate innovation with the ecological environment, so as to enhance the green innovation capabilities of Hebei’s high-tech industries.

2. The connotation of green innovation ability
At present, scholars at home and abroad have defined the connotation of innovation ability from different perspectives and different levels, but there is no unified standard for the definition of green innovation ability. This study holds that green innovation ability is guided by sustainable development, and must embody the principles of innovation, ability and sustainable development, among which capacity is the basis, innovation is the core, and green is the condition. According to this study, the green innovation ability refers to the process and results of its innovation should be the main evaluation index of green innovation ability, and at the same time, the improvement of enterprise competitiveness is the basic starting point, and the resources in all aspects are integrated and utilized, thus forming various comprehensive capabilities. It is necessary to emphasize that the difference between green innovation ability and general innovation ability is that green innovation ability focuses on the concept of green sustainable development, which not only reflects the level of industrial innovation input and industrial innovation output, but also reflects green development. The ability of green innovation promotes the optimization of industrial green innovation and green environmental protection, so as to realize the ability of high-quality development of regional economy.

3. Green development status of high-tech industry in Hebei province
With the rapid development of high-tech industry in Hebei Province, the industrial scale is gradually expanding, and the problem of green development is becoming more and more prominent.

3.1. Innovation investment
From the perspective of innovation input, during 2009-2018, the internal R & D expenditure of high-tech industry in Hebei Province increased from 758 million yuan to 4.36 billion yuan, an increase of nearly six times in ten years. The expenditure of new product development in Hebei Province in 2018 was 5.035 billion yuan, 7 times of that in 2009, significantly higher than other inputs. Although the internal R & D expenditure of high-tech industry in Hebei Province and the strength of new product research and development continue to expand, compared with other provinces, Hebei Province is in the middle and lower level, which indicates that Hebei Province needs to continue to increase R & D funds and new product development funds, so as to make Hebei Province's high-tech industry science and technology content higher.

3.2. Innovation output
From the perspective of innovation output, during 2009-2018, the number of patent applications for high-tech industry in Hebei Province increased from 481 to 1633. Compared with other provinces, the number of patent applications in Hebei Province is relatively small. The high-tech industry in Hebei Province needs to continue to improve and increase the number of patent applications. Invention patent is the advantage of the industry and the key to the green development of the industry. In 2018, the sales revenue of new products of high-tech industries in Hebei Province was 52617.34 million yuan, 9 times higher than that in 2009, with an average growth rate of 29.3% over the past ten years. This shows that the pace of R & D of new products in high-tech industries in Hebei Province is accelerated, the speed of technological innovation is increasing, the economic benefits brought by the marketization of scientific research achievements are more and more prominent, and the impact of innovation on economic growth is becoming more and more important.

3.3. Innovation environment
From the perspective of innovation environment, during 2009-2018, the per capita GDP increased from 25000 yuan to 43000 yuan, which was relatively small compared with other provinces. There is still a lot of room for the development of high-tech industry in Hebei Province. The number of broadband Internet access ports in Hebei Province has increased year by year, from 6.791 million in 2009 to 41.924 million in 2018, an increase of 6 times in recent ten years. With the change of economic development mode, in order to meet the needs of economic development and people's life in Hebei Province, Internet broadband access ports are gradually increased. The number of health
technical personnel per 1000 population in Hebei Province has increased year by year, from 3.89 in 2009 to 6.1 in 2018, nearly twice the growth in ten years. According to the original data, the health technical personnel per thousand population in Hebei Province has been lower than the national average level, which indicates that Hebei Province needs to further strengthen the development of medical conditions and build a good infrastructure for the innovation and development of green technology.

3.4. Green development

From the perspective of green development, the investment level of pollution control has affected the green development degree of high-tech industries in Hebei Province. In 2018, the investment in environmental pollution control in Hebei Province was 3427.38 million yuan, accounting for 5% of the whole country, which was at a low level in the national pollution control. The output level of pollution emission reflects human's awareness of environmental protection and affects the green degree of Hebei Province's development. In 2018, the solid waste output of Hebei Province was 327.21 million tons, accounting for 9.8% of the whole country, indicating that the pollution emission of Hebei Province is at a high position in the country, affecting the development of green innovation in Hebei Province. We should continue to strengthen environmental protection publicity, enhance the awareness of enterprise emission reduction, and promote the green development of high-tech industry in turn.

By comparing the data of innovation and development of high-tech industry in Hebei Province for 10 years, it can be seen that the high-tech industry in Hebei Province is developing continuously, but compared with other developed provinces, Hebei Province is in the middle and low level, which shows that there are great development advantages in the green development of high-tech industry in Hebei Province. Through the following empirical analysis, the corresponding policy recommendations are put forward.

4. Construction of index system of green innovation ability of regional high tech industry

Scientific and reasonable construction of the evaluation index system of regional high-tech industry green innovation ability is the premise and foundation of correctly evaluating regional high-tech industry green innovation ability. Therefore, the design of evaluation index system should follow the principles of scientificity, comprehensiveness, objectivity, feasibility and systemicity.

4.1. Construction of index system of green innovation ability of regional high tech industry

Based on the comprehensive analysis and comparison of various factors affecting the green innovation ability of regional high-tech industry, the evaluation index system of regional green innovation capability is established (see Table 1).

1) Green innovation investment capacity. The successful development of regional high-tech industry green innovation activities needs a lot of innovation resources, and green innovation investment is the premise of the successful realization of green innovation. The input of green innovation includes human input, material input, financial input and pollution control input. It is closely related to the output capacity of green innovation. It is the basic element of the green innovation system and an important driving factor to enhance the green innovation ability of regional high-tech industries.

2) Green innovation output capacity. The green innovation output capacity of regional high-tech industry is an efficiency index reflecting the transformation of green innovation input into green innovation output. In addition to the positive indicators reflecting the output of scientific and technological achievements and economic benefits, this paper also adds the negative index of pollution emission output in the process of green innovation, so as to further improve the green innovation output capacity of regional high-tech industry.

3) Green innovation environment capability. In the whole process of green innovation of high-tech industry, green innovation is affected by economic development, national policy support and social
harmony. The national economic development and a series of policies and systems have greatly promoted the sustainable green innovation of regional high-tech industries.

**Table 1.** Evaluation index system of green innovation ability of regional high tech industry.

| First-level index | Secondary index | Tertiary index |
|-------------------|-----------------|----------------|
|                   | Green innovation investment capacity | |
|                   | Manpower input  | Number of personnel in R&D activities X1 |
|                   |                 | Research and development (R&D) personnel equivalent full time equivalent X2 |
|                   |                 | The proportion of high-tech industry employees in total employees X3 |
|                   |                 | Average number of students in higher education institutions per 100000 population X4 |
|                   | Financial input | R&D expenditure of high-tech industry X5 |
|                   |                 | R&D investment intensity X6 |
|                   |                 | Expenditure on research and development of new products X7 |
|                   | Material input  | Number of high-tech enterprises X8 |
|                   |                 | Number of research and development institutions X9 |
|                   | Investment in pollution control | Total collection of Public Library X10 |
|                   |                 | Investment in environmental pollution control X11 |
|                   |                 | Investment in environment pollution waste water X12 |
|                   |                 | Environmental pollution waste gas investment X13 |
|                   | Output of scientific and technological achievements | The number of Chinese scientific and technological papers collected by foreign man retrieval tools X14 |
|                   |                 | Number of valid invention patents X15 |
|                   |                 | Number of new product development projects X16 |
|                   | Economic benefit output | Total profit of high-tech industry X17 |
|                   |                 | Sales revenue of new products X18 |
|                   |                 | Total export volume of new products X19 |
|                   | Pollution emission output | Total industrial waste water discharge X20 |
|                   |                 | Industrial solid waste production X21 |
|                   |                 | Emission of smoke(powder)and dust in industrial waste gas X22 |
|                   | Economic development | Per capita GDP X23 |
|                   | Social harmony   | Per capita consumption expenditure of residents X24 |
|                   |                 | Per capita park green area X25 |
|                   |                 | Health professionals per 1000 population X26 |
|                   |                 | Medical insurance coverage X27 |
|                   | Policy support   | Per capita labor cost of R&D personnel X28 |
|                   |                 | Government funds in R&D expenditure X29 |
|                   |                 | Education expenditure X30 |


4.2. Selection of evaluation method

At present, there are many comprehensive evaluation methods of green innovation capability at home and abroad, which can be divided into two categories: subjective weighting evaluation method and objective weighting evaluation method. Since the data of green innovation capability index system of high-tech industry constructed in this paper are all from the statistical yearbook, due to the quantifiable data, objective weighting evaluation method can be adopted. Compared with the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation (FCE), the results of factor analysis are more objective. The data in the index system constructed in this paper are all from China's high-tech industry statistical yearbook and China's science and technology statistical yearbook, which can be quantified and used objective weighting method. The index system constructed in this paper is divided into three levels, including 30 specific indicators. In order to avoid the weight problem that subjective determination may lead to large error, factor analysis is appropriate. The specific steps are as follows:

4) Test whether the data is suitable for factor analysis. KMO>0.5, suitable for factor analysis. KMO<0.5 means failing the test. Sig<0.01, indicating that the imported index has a significant correlation. When Sig<0.01, the index correlation is poor.

5) Calculate the correlation coefficient matrix R of regional tourism potential variables. Let the characteristic equation |R−λ|=0, calculate the characteristic value λ and the characteristic vector X (X=1, 2, ..., n).

6) Build the initial factor loading matrix. Whether the cumulative variance contribution rate value is greater than 70% is used as the criterion for testing. Establish the initial factor loading matrix A according to the eigenvalues and eigenvectors calculated in the previous step.

\[ A = (X \times \sqrt{d_i})_{m \times n} = (a_{ij})_{m \times n} \]

7) The rotation factor loading matrix makes the relationship between the rotated common factor and the variable more clear.

8) Calculate the score of each factor.

\[ F_1 = a_{11}P_1 + a_{12}P_2 + \ldots + a_{1m}P_m + a_1 \epsilon \]
\[ F_2 = a_{21}P_1 + a_{22}P_2 + \ldots + a_{2m}P_m + a_2 \epsilon \]
\[ \vdots \]
\[ F_n = a_{n1}P_1 + a_{n2}P_2 + \ldots + a_{nm}P_m + a_n \epsilon \]

In the formula, F1, F2,...Fn are the standardized initial variables, P1, P2,...Pm are factor variables, \( \epsilon \) are residual factors.

9) Calculate the comprehensive score. The contribution rate of each main factor in the cumulative variance contribution rate is used as the weight to calculate the comprehensive score.

5. Empirical research

5.1. Sample selection and data sources

The data in this paper are from China high tech industry statistical yearbook, China Science and technology statistical yearbook and China Statistical Yearbook in 2019. According to the Yearbook, the above 30 index data of 31 provinces / cities / autonomous regions in 2018 are sorted out (except for Hong Kong, Macao and Taiwan regions with missing data). For some indicators data missing in Xinjiang, Qinghai, Ningxia and other regions, two processing methods are adopted. One is to replace the index data of the previous year, and the other is to replace it with the weighted average of the index of neighboring provinces. Spss26.0 software is used for data processing. Firstly, the original data is standardized. The total amount of waste water, the amount of smoke (powder) and dust in the waste gas and the production of industrial solid waste are all reverse indicators. Therefore, they should be treated positively first. The positive treatment method selected in this paper is to take the reciprocal.
5.2. Evaluation results

Guangdong, Jiangsu, Beijing, Zhejiang and Shanghai are the regions with higher scores of green innovation ability (see Table 2). The comprehensive ranking of green innovation ability of high-tech industry in Hebei Province is 17, which is lower than the total level. In addition, the green innovation input of high-tech industry in Hebei Province ranks 17th in China, the output of green innovation of high-tech industry in Hebei Province ranks 23rd in China, and the green innovation environment of high-tech industry in Hebei Province ranks 15th in China. It shows that the green technology innovation ability of high-tech industry in Hebei Province is in the lower middle position, and there is a big gap compared with the developed areas.

Guangdong, Jiangsu, Zhejiang, Shanghai, Beijing and other provinces and cities rank top in the green innovation ability of high-tech industries. These provinces and cities are economically developed areas in China, and have strong innovation support on the whole, such as economic foundation, human resources and technological resources, etc., so the green innovation ability of high-tech industries in these regions develops rapidly. Anhui, Sichuan, Tianjin, Hunan, Hubei, Chongqing and other provinces and cities are in the general position of green innovation ability. Relying on their own advantages, these provinces and cities continue to attract high-tech industrial enterprises to settle in. However, due to the lack of economic foundation and technical resources, the development of green technology innovation ability is limited. Shanxi, Inner Mongolia, Yunnan, Xinjiang, Tibet and other provinces are relatively backward in economic development and inconvenient transportation, which makes it difficult for green innovation of high-tech industries to develop rapidly.

Table 2. Evaluation results of regional high tech industry green innovation.

| Overall ranking | area           | Tourism industry development potential overall ratings | Tourism industry supply potential Score | Tourism market demand potential Score | Tourism environment support potential Score |
|-----------------|----------------|------------------------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------------|
| 1               | Guangdong Province | 4.095                                                | 2.616                                 | 3.439                               | 1.054                                       |
| 2               | Jiangsu Province  | 1.785                                                | 1.215                                 | 1.226                               | 0.621                                       |
| 3               | Beijing City      | 1.287                                                | 0.059                                 | 0.246                               | 1.979                                       |
| 4               | Zhejiang Province | 1.145                                                | 0.720                                 | 0.611                               | 0.627                                       |
| 5               | Shanghai City     | 0.724                                                | 0.162                                 | 0.203                               | 0.903                                       |
| 6               | Shandong Province | 0.610                                                | 0.525                                 | -0.024                              | 0.484                                       |
| 7               | Fujian Province   | 0.217                                                | 0.104                                 | 0.142                               | 0.098                                       |
| 8               | Sichuan Province  | 0.149                                                | 0.030                                 | -0.001                              | 0.228                                       |
| 9               | Hubei Province    | 0.139                                                | 0.092                                 | -0.001                              | 0.140                                       |
| 10              | Tianjin City      | 0.020                                                | -0.115                                | 0.007                               | 0.162                                       |
| 11              | Shanxi Province   | -0.053                                               | -0.084                                | -0.202                              | 0.187                                       |
| 12              | Henan Province    | -0.065                                               | -0.120                                | 0.224                               | -0.180                                      |
| 13              | Anhui Province    | -0.131                                               | 0.043                                 | -0.045                              | -0.239                                      |
| 14              | Chongqing City    | -0.140                                               | -0.246                                | 0.073                               | -0.029                                      |
| 15              | Hunan Province    | -0.170                                               | 0.121                                 | 0.006                               | -0.236                                      |
| 16              | Jiangxi Province  | -0.390                                               | -0.121                                | -0.159                              | -0.402                                      |
| 17              | Hebei Province    | -0.436                                               | -0.153                                | -0.297                              | -0.156                                      |
| 18              | Liaoning Province | -0.447                                               | -0.148                                | -0.024                              | -0.105                                      |
| 19              | Jilin Province    | -0.499                                               | -0.332                                | -0.220                              | -0.293                                      |
| 20              | Guizhou Province  | -0.526                                               | -0.313                                | -0.270                              | -0.317                                      |
| 21              | Shanxi Province   | -0.550                                               | -0.316                                | -0.717                              | -0.437                                      |
| 22              | Inner Mongolia Autonomous | -0.570                        | -0.280                           | -0.775                              | 0.010                                       |
| Region                          | Score       |
|--------------------------------|-------------|
| Gansu Province                 | -0.586      |
| Hainan Province                | -0.589      |
| Ningxia Hui Autonomous Region | -0.608      |
| Guangxi Zhuang Autonomous Region | -0.643      |
| Heilongjiang Province          | -0.688      |
| Xinjiang Uygur Autonomous Region | -0.689      |
| Yunnan Province                | -0.783      |
| Qinghai Province               | -0.786      |
| Tibet Autonomous Region        | -0.821      |

### 6. Conclusions

This paper uses the factor analysis method to evaluate, analyze and compare the green innovation ability of high-tech industry in each province, and draws the following conclusions:

1. The green innovation ability of high-tech industry in Hebei Province is constantly improving, but the overall score is low, and there is a big gap compared with developed areas. The investment of green innovation talents is low, the overall score of green innovation ability of high-tech industry in Hebei Province is low. The main reason for this.

2. The short board of green innovation ability of high-tech industry in Hebei Province is the ability of green innovation environment, the main reason is the weak driving capacity of green innovation.

3. The investment capacity of green innovation funds also affects the green development of high-tech industries in Hebei Province, including new product R & D funds, R & D funds and so on. Accordingly, we can make the following suggestions:

#### 6.1. Improve the talent training system and enhance Hebei’s innovation strength

Hebei Province is geographically close to Beijing and Tianjin, and some talents flow to Beijing, Tianjin and other places, resulting in a serious loss of talent resources in Hebei Province. First of all, the development of green innovation in Hebei’s high-tech industry is inseparable from the investment of human capital. While introducing talents from other regions in the environment protection industry, it is necessary to focus on the training and continuing education of existing employees, so that talents can be maximized and jointly contribute to Hebei. Provincial high-tech industry green innovation development efforts. Second, Hebei’s high-tech industrial enterprises can enter universities, establish cooperation with surrounding universities, and use the mechanism of combining campus talents with enterprises to increase the conversion rate of scientific and technological achievements. Third, establish quantifiable evaluation indicators for innovation talents, and conduct regular assessments of talents, so that high-quality talents can truly realize their own value in the development of green innovation in Hebei’s high-tech industry.

#### 6.2. Carrying out the concept of green innovation and boosting the development of high-tech industry

Green innovation is the fundamental guarantee to promote the coordinated development of nature and economy, an important action to build a harmonious society, and a powerful tool to realize sustainable development. First, the government regularly publicizes green development and green technology for the public, so that the public can understand the importance of green consumption, form a good green lifestyle, and improve a good innovation environment for high-tech industries. Second, improve and implement the green innovation policy. Hebei provincial government should establish relevant policies,
subsidies and rewards should be given to enterprises implementing green innovation, and products that
seriously do not conform to the concept of green development should not be allowed to enter the
market, so as to jointly build a green innovation market. Third, the high-tech industry enterprises
should further strengthen the dominant position of green innovation, realize the importance of the
development of green innovation to high-tech industry and high-quality economic development,
realize the high-tech industry vigorously can promote green innovation and drive the green
development of other industries.

6.3. Increase the intensity of innovation investment to lay a solid foundation for green development
The key to green development of high-tech industry lies in innovation. However, it needs a lot of
manpower, material and financial resources. First of all, the R & D investment of high-tech industry
should focus on the R & D of green emerging technologies, strive to achieve major breakthroughs in
key technologies, and strengthen the application and promotion of these green technologies in the field
of green economy. Secondly, research of the market demand at home and abroad can find new green
growth point of the economy, strengthen technical research, transform market demand into
commercial products, and build a technical support system for green development. Third, green
technology research and development should combine green technology introduction with independent
innovation, strive to break through the bottleneck of innovation technology, and realize the green
economic development system of economic and ecological integration and symbiosis.

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