Influencing Factors and Evaluation of Green Innovation Efficiency: A Literature Review

Wangmin Lu
International Business School, Shaanxi Normal University, Xi'an 710000, China.
luwangmin1996@163.com

Abstract. As the combination of two national development strategies of innovation-driven and green development, green innovation has become the focus of attention from the community. Comprehensively and effectively improving the efficiency of green innovation is an important way for China to ensure the growth rate while conserving resources and energy. It is also an important guarantee for China in the stage of high-quality economic development. Therefore, this paper focuses on the term "green innovation efficiency". Based on the related concept of green innovation, this paper reviews and comments on the efficiency evaluation of green innovation from aspects, such as influence factors, evaluation methods and evaluation indicator system. It aims to provide theoretical reference for policy makers in green innovation strategies and optimization of innovation resource allocation, so as to improve the efficiency of green innovation effectively.

Keywords: Green innovation efficiency; influence factors; literature review.

1. Introduction

The reform and opening up, which began in 1978, has brought rapid economic growth to China. However, China's economic development in the past mainly relied on extensive economic development model, which results in poor quality of growth, weak innovation capacity and high cost of resources and environment. It is an inevitable choice for China to change the concept and mode of development. Green innovation combines the two national strategies of innovation-driven and green development, which bring economic and environmental rewards at the same time. To comprehensively and effectively improve the efficiency of green innovation is an important way for China to ensure the growth rate and save resources and energy at the same time. It is also an important guarantee for China's high-quality economic development.

2. Relevant Concepts

2.1 Green Innovation

Green innovation is often confused with the concepts of "ecological innovation" and "sustainable innovation". Kemp defines environmental innovation as new or improved processes, technologies, systems and products resulting from the avoidance or reduction of environmental damage [1]. Hellström points out that compared with environmental innovation, sustainable innovation is a broader concept, which includes not only brand new products that can reduce environmental impact, but also products that can improve other aspects of human life [2]. Fussier defines eco-innovation as a new product or process that can bring business value to customers, and at the same time reduce the impact on the environment [3]. Kusz emphasized that environmental factors should be considered in the whole process of product innovation, and proposed the concept of green technology innovation process [4]. The term green innovation appears for the first time in the book driving green innovation by Fussler and James. Beise and Rennings argue that green innovation refers to the adoption of relatively new and improved technologies, processes, practices, systems and products by enterprises in order to minimize environmental hazards. Chen Huabin defined the creative activities carried out by people to coordinate the development of society, economy and environment as green innovation. Ying Ruiyao and Zhou Li believe that all creative activities that can promote the coordinated development of energy-economy-environment system can be called green innovation. Zhang Gang and Zhang Xiaojun summarized three definitions of green innovation in “Several Basic Issues of Green Innovation Research”.

To sum up, "sustainability" emphasizes the fairness and efficiency of inter-generation, while ecological innovation emphasizes the fairness and efficiency of economic and ecological environment of the same generation. However, green innovation contains both of these meanings. Although there are slight differences, the above four concepts have the same meaning to a large extent. Many scholars believe that these four concepts are equivalent and have been replaced in literature.

2.2 Green Innovation Efficiency

Traditional innovation efficiency does not consider the impact on the environment, while green innovation efficiency is the innovation efficiency that comprehensively considers the environmental cost in the process of input and output of innovation resources. Green innovation efficiency refers to the greening degree of regional innovation efficiency and measures the quality of innovation development after comprehensive consideration of environmental pollution and energy consumption.

3. Influencing Factors

Many achievements have been made in the field of influencing factors of green innovation. Some scholars focus on the influence of single factor on green innovation.

Porter proposed that appropriate environmental regulations can stimulate technological innovation and enable enterprises to gain market competitive advantages, so as to promote green innovation. Panda points out that if the environmental regulation intensity is too heavy, the overall R&D level of enterprises will be reduced and green innovation will be hindered. Reis argues that foreign direct investment (FDI) can promote green innovation by reducing innovation costs in the receiving countries. Bi Kexin et al. believe that FDI inflow has a significant positive impact on green R&D capacity and green manufacturing capacity, and a negative impact on the market development capacity of green products. Hurley et al. believe that increasing investment in human resources and improving independent innovation ability of enterprises will also promote the development of green innovation. Hong Junjie and Shi Lijing found that there is a significant positive correlation between independent research and innovation performance.

Some scholars have comprehensively investigated the influence of multiple influencing factors on green innovation.

Hua Zhen concluded that improving human capital quality, improving R&D intensity and increasing investment in environmental pollution control are all conducive to the development of green innovation, while high degree of trade openness will inhibit the development of green innovation. Cao Xia et al. analyzed and concluded that regional openness, technology market maturity and government funding play a positive role in promoting the validity of green innovation. Gao Guangkuo et al. showed that regional economic level, scientific and technological innovation environment, level of opening-up and FDI all had significant positive impacts on green innovation of energy-consuming industries, resource endowment had significant negative impacts, and enterprise size had no significant impact. The research results of Li Yuting et al. showed that: regional green innovation efficiency is positively correlated with various systems. Among them, intellectual property, finance, environment and financial system have significant influence, especially the influence of financial and financial system is sensitive, while the influence of basic legal system is not significant.

In general, the above factors can be classified into two categories: external environmental factors and internal driving factors. The study of external environmental factors depends on institutional theory, market theory and so on. In terms of internal driving factors, enterprise R&D investment, internal personnel quality, and internal management level constitute the basis of enterprise green innovation activities.

4. Evaluation Methods

There are many evaluation methods for green innovation efficiency. The evaluation methods for studying green innovation efficiency are mainly divided into parametric method and non-parametric method. The parametric method is mainly Stochastic Frontier Analysis (SFA), and the non-parametric method is mainly Data Envelope Analysis (DEA). Some scholars have also adopted other methods for research, which have not become the mainstream methods due to their own defects.

4.1 The Mainstream Approach

4.1.1 SFA Stochastic Frontier Analysis

The stochastic frontier analysis method needs to determine the specific form of production function and considers the influence of random factors on output. Xiao Wen et al. and Xiao Liming et al. adopted the stochastic frontier analysis method.

4.1.2 DEA Data Envelopment Analysis

This method requires no prior setting of function form, is simple to operate, and the evaluation result is relatively objective, so it is the main measure method of green innovation efficiency, but ignores the influence of random factors. Han Jing used DEA to measure and analyze the green innovation capacity of 30 provinces, autonomous regions and municipalities in mainland China.

4.1.3 All Kinds of Extended Models of DEA Model

SBM (DEA-SBM). The traditional DEA model is a radial model, and the problem of slack variables is not considered. Tone proposed an SBM model containing undesired outputs to solve this problem. Feng Zhijun, Yin Qun et al. used the SBM model to measure the efficiency of green innovation.

Super DEA model. Efficiency evaluation results of traditional DEA model can be divided into two categories: effective and invalid. There are often multiple DMUs that are effective, and no further sorting and comparison can be performed. Andersen et al. proposed the super-efficient DEA model, which solved many problems that could not be further compared with other effective decision-making units.

Super SBM model. A model that combines super-efficiency with the SBM model is also taking slack variables into account. Wang Hui, Wu Chuanqing et al. used the Super-SBM model to measure the efficiency of green innovation.

Super-SBM-Windows. In the evaluation of efficiency, for panel data, many literatures use the cross-section data of each period to evaluate the static efficiency, and then dynamically compare the results of each period. This approach is lacking because the production frontiers of each period are not the same, the efficiency values are only comparable in the current period, and there is no dynamic comparability during the inter-period. Charnes et al. proposed a DEA-Windows analysis for this problem. Liu Mingguang constructed the Super-SBM-Windows method for green innovation efficiency evaluation of regional innovation systems in China.

DEA-RAM model. The model overcomes many of the shortcomings of the traditional DEA model and has the characteristics of non-radial, non-angle and additive structures. Ren Yao et al., Yao Xilong et al. used this model to measure the efficiency of green innovation.

DEA-Malmquist index. This method is mainly to combine the advantages of both. Liu Haiying et al. based on the DEA-Malmquist model for the empirical analysis of green technology innovation efficiency in China's paper industry.

Multiple stage DEA. Fried et al. innovatively proposed a four-stage DEA model. Niu Tong et al. studied the green innovation efficiency of industrial enterprises in Shanxi Province based on SBM-DEA four-stage method. Fried et al. proposed a three-stage DEA model based on the four-stage method, while Li Xiaoyang et al. evaluated the industrial green innovation efficiency of China's provincial regions based on the SBM-DEA three-stage method.

4.2 Nonmainstream Methods

Niu Tong et al. believe that some methods have not become the mainstream methods to evaluate the efficiency of green innovation due to their own defects.

4.2.1 Structural Equation Method

Wang Jianming et al. used Structural Equation Modeling (SEM) to study the mediating effect of enterprise green innovation activities.

4.2.2 Factor Analysis Method

Hua Zhen used factor analysis method to compare and study the green innovation performance of 30 provinces in China in 2009, and emphatically analyzed the situation of the three northeastern provinces.

Table 1. Evaluation methods combing

Literature	Period	Research method	Research object
Xiao Wen et al. (2014)	2000-2009	SFA	36 industrial sectors
Han Jing (2012)	2005-2010	DEA	30 provinces in mainland China
Feng Zhijun (2013)	2008-2009	DEA-SBM	30 provincial regions
Wu Chuanqing et al. (2019)	2005-2015	Super -SBM model	equipment manufacturing industry
Ren Yao et al. (2014)	2001-2013	DEA-RAM	industry in 11 prefecture-level cities in Shanxi Province
Liu Haiying et al. (2011)	2001-2010	DEA-Malmquist index	China's paper industry
Niu Tong et al. (2015)	2006-2012	Multiple stage DEA	industry in Shanxi Province

5. Evaluation Indicator System

Based on mainstream evaluation methods and influencing factors, most scholars select evaluation indexes of green innovation efficiency from the perspective of input and output.

5.1 Input Indicators

There are usually two trends in the selection of human and financial indicators in existing literature. One is R&D personnel investment and R&D expenditure. Another, the investment in scientific and technological activities and the expenditure on scientific and technological activities. Feng Zhijun adopted this indicator. In addition, Cao Xia adopted the R&D capital stock as an input indicator. The index of material input usually adopts the original price of microelectronic control equipment, instrument and equipment, and so on. Feng Zhijun adopted the original price of microelectronic control equipment.

Energy investment indicators. Yin Qun et al. used the total production energy coal consumption of ten thousand yuan in each region as the resource input factor. Liu Liang et al. choose the total energy consumption converted into standard coal as the input to measure the efficiency of industrial green innovation. Li Ling et al. conducted research on the green innovation efficiency of pollution-intensive industries as the energy input data of the total energy consumption of the sub-sector.

5.2 Output Indicators

Expected output refers to the maximum profit that every enterprise hopes to obtain, while non-expected output refers to the output accompanied by non-economic efficiency when an enterprise obtains expected output, such as ecological damage and environmental pollution. Han Jing, Luo Liangwen et al. regard the emission of environmental pollutants as an input factor.

5.2.1 Expected Output Indicators

Scholars choose the number of invention patent applications as an indicator to measure the potential market benefits and value realization of enterprise green innovation. Other supplementary indicators such as sales revenue of new products and output value of new products will be selected to measure the economic benefits of green innovation. Indicators such as industrial output value take into account that innovation can not only produce new products, but also the application of new technologies is beneficial to the improvement of enterprises' previous products and processes. Li Ling et al. used the industrial output value of identified pollution-intensive industries as the expected output.

5.2.2 Non-expected Output Indicators

Currently, scholars mostly adopt energy consumption per unit of industrial added value, industrial sulfur dioxide emissions, industrial water consumption, environmental pollution index, carbon emissions, energy consumption per unit of regional GDP. Enterprises in different industries produce different pollutants, so the selection of non-expected output indicators will be different.

6. Conclusions and Prospects

Through literature review, the following conclusions can be drawn. First of all, in terms of the influencing factors of green innovation, there are many studies on external environmental factors, and the research on internal factors of enterprises is less, and the interaction between various influencing factors has not been paid much attention. Secondly, it can be seen that although the current evaluation methods of green innovation efficiency are diverse, the research objects mainly involve industries with close energy consumption and environmental pollution, such as industry (or manufacturing industry), and less involved in other industries. Finally, the current green innovation efficiency has more research on regional and inter-provincial comparisons, while there are few comparative studies between countries, industries and enterprises.

Therefore, we should expand from these aspects after the research. It is necessary to carry out relevant research on other industries and achieve comprehensive coverage of green innovation research. Not only should we focus on the comparison of green innovation efficiency among provinces and regions, but also the comparison between countries, industries and enterprises.

References

[1]. René Kemp, Smith K, Becher G. How should we study the relationship between environmental regulation and innovation?. ZEW Economic Studies. Vol. 10 (2000) p. 43-66.

[2]. Hellström Tomas. Dimensions of environmentally sustainable innovation: the structure of eco-innovation concepts. Sustainable Development. Vol. 15 (2007) No. 3, p. 148-159.

[3]. Fussier C, James P. Book review: driving eco-innovation: A breakthrough discipline for innovation and sustainability. Pitman Pub, 1996, p. 297-297.

[4]. KUSZ. Integrating environmental goals and the product development process. The Design Actions and Resources for the Environment Conference Proceedings. Boston,Mass,USA, 1991, p. 8-11.