Research on Evaluation and Factors of Regional Green Innovation Performance Based on ER-XIANG Dual Theory

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Abstract. On the basis of panel data from 30 provinces during 2005-2014, the index system of regional green innovation performance is built from efficiency and output two dimensions based on dual theory. The evaluation of regional green innovation performance is using PPE-Malmquist-LWN model synthetically and the empirical analysis is used to study on factors of regional green innovation performance. The results indicate that regional green innovation performance shows an M type trend, and in east is higher than that in west. On the whole, FDI, ODI, environmental regulation of lag 1 have positive effects on regional green innovation performance, but internal and externa l market needs, intellectual property protection, market institutions have negative effect. In eastern region, FDI, external market needs, market institutions have negative effect, but environmental regulation of lag 1 has positive effects. In central region, internal market needs has negative effect, but ODI and environmental regulation of lag 1 have positive effects. In western region, internal market needs and intellectual property protection have negative effect, but FDI, ODI and external market needs have positive effects.

1. Introduction

With the continuous development of economic globalization and the increasing problem of resource and environment, green innovation has become the decisive force for the sustainable development of the global economy. The Chinese government emphasizes the coordinated development of economic and social and eco-environmental systems by the implementation of green innovation nowadays. To China's vast territory, regional resources endowment differences affect the balanced development of regional economy and the regional coordinated development of resources and environment. Therefore, the accurate evaluation of regional green innovation performance will help understand the green innovation performance gap with similar regions, and clearly enhance the influencing factors of green innovation performance and promote the sustainable development of China.

At present, domestic and foreign scholars have obtained more research achievements in the research of green innovation performance evaluation and its influencing factors. In terms of the performance evaluation of green innovation, most of the literatures are from the perspective of output of green innovation performance evaluation index system, and then using the factor analysis model(Cheng and Liao, 2011) [1], projection pursuit model(Bi et al., 2013) [2], the Super - SBM model(Wang et al., 2016) [3]to comprehensive evaluation method, the main difference lies in the different index system.

The index system constructed includes three dimensions: ecological organization, ecological technological innovation and eco-product innovation (Cheng and Shiu, 2012) [4]. However, green innovation performance evaluation index system constructed by management innovation, technological innovation, product innovation and technological innovation(Tseng et al., 2013) [5].

Some literatures use DEA and its derivative methods to calculate the input-output efficiency of green innovation from the perspective of efficiency. (Wang et al., 2016) [3].

In the study of the influence factors of green innovation, environmental regulation is considered to be one of the most important influence factors, but the effects of environmental regulation on green innovation performance remains controversial. Researchers finds that environmental regulation promotes green innovation performance by changing the green behaviour of enterprises (Huang et al., 2016) [6]. And the research results of a group shows that the pollutant discharge permit system and the time limit governance system in the environmental system have negative impacts (Fan et al., 2013) [7]. However, A typical research shows that there is a u-shaped relationship between environmental regulation and innovation(Shen et al., 2012) [8]. In addition, the market needs(Zailani et al., 2015) [9], technological advancements (Fan et al., 2013) [7], environmental management systems(Cuerva et al., 2013) [10], customer stress and corporate green response behaviours(Huang et al., 2016) [6]are also thought to be a key factor in promoting the performance of green innovation.

To sum up, the existing literature has achieved many findings on green innovation performance evaluation and influencing factors, but we believe that it could be improved in the following aspects: firstly, the evaluation result based on the single perspective of output or efficiency may lead to the false positive judgment of green innovation performance; Secondly, the green innovation performance influence factors are relatively random, lacking of comparison in the influence factors of green innovation performance among different regions.

Therefore, we use 30 provinces panel data during 2005-2014, based on the duality characteristics of the perspective of output and efficiency to build green innovation performance evaluation index system, using the PPE - Malmquist - LWM model for comprehensive evaluation; Then, the influence factors of green innovation performance were extracted from the relatively intact framework, and the differences of the influence factors were analysed from the whole, eastern, central and western regions. It is of great practical significance to accurately grasp the status of green innovation performance and its influence factors in various provinces of China, and to formulate the policy of green innovation.

2. Research on the Performance Evaluation of Regional Green Innovation Based on ER-XIANG Dual Theory

2.1. Regional green innovation performance evaluation index system based on ER-XIANG duality

Based on the wave particle duality and system theory, we argue that green innovation performance can be divided into two dimensions: green innovation output and green innovation efficiency, namely, the two image characteristics of green innovation performance. In this case, the green innovation is the actual dimension of green innovation, which are the socioeconomic performance and the environmental benefit including the output of green patents, the technical skills, the knowledge of the products, the value of the new product sales, and the output of the green innovation. Green innovative output represents the quantitative result of green innovative performance from the perspective of "quantity", and it is a static evaluation on green innovation performance. Green innovation efficiency is a virtual image of green innovation performance, reflecting the effectiveness of the process management of green innovation activities. It is the ability of green innovation subjects to integrate and coordinate various green innovation resources into new products, new technology and new services in the green innovation activities. In the evaluation, green innovation efficiency is reflected in the input and output relationship of green innovation activities, reflecting the process management level of technological innovation performance from the perspective of "quality". In a word, the higher the green innovation performance is not only characterized by high green innovation output, also show the good efficiency of green innovation. According to the above analysis, the green innovation performance evaluation indicator system based on ER-XIANG Dual theory includes two first-grade indexes: green innovation output and green innovation efficiency. Among them, secondary indicators of green innovation output includes green patent application quantity, new product sales revenue, technology market turnover, pollutant discharge fee of unit industrial output value, energy consumption in unit area output value, industrial waste removal rate, industrial waste generation intensity and industrial waste recycling rate; The green innovation efficiency is calculated by the input and output index, and the secondary indicators of green innovation inputs include the R&D capital

investment, the new product development costs, the environmental pollution management investment, the technology import and the technology modification costs, full time equivalent of R&D personnel and the number of stuff in the environmental protection system at the end of the year.

2.2. Evaluation model based on PPE-Malmquist-LWM

The PPE-Malmquist-LWM model was used to evaluate green innovation output, green innovation efficiency and green innovation performance. Projection tracing (PPE) is an exploratory data analysis method driven directly by sample data and is particularly suitable for analysing and processing non-linear and non-normal high dimensional data. The projection tracking evaluation model is used for comprehensive evaluation. Calculating the projection pursuit direction is a complicated nonlinear optimization problem, so it is difficult to be solved by the traditional optimization method. Therefore, we use the real-coded accelerating genetic algorithm (RAGA) to find the best projection direction. Based on the existing literatures, we also select the Malmquist index method to measure the efficiency of green innovation from the perspective of the effectiveness of green innovation input and output. The Malmquist index method is a dynamic comparison way based on the relative validity of the DEA model. It uses the ratio of distance function to calculate the input-output efficiency, which reflects the change of input-output efficiency from t period to t+l period.

2.3. Regional green innovation performance evaluation and result analysis.

Based on the above theory, this paper makes an empirical assessment on green innovation performance of our 30 regions in 2005-2014. From the time dimension, we can see the overall green innovation performance evaluation average represented M type volatility growth during 2005-2014 in figure 1.

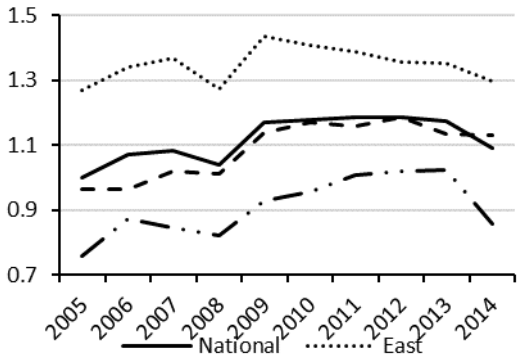

Figure 1. Regional green innovation performance

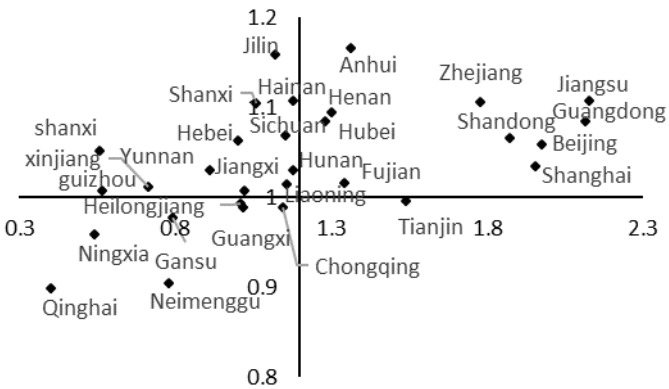

Figure 2. Regional green innovation performance spatial distribution based on ER-XIANG Dual Theory.

From the perspective of the dual characteristics of regional green innovation performance (figure 2, the horizontal axis output =1.198, vertical axis efficiency =1), the green innovation efficiency of 73.33% in the country is in the progressive state (i.e., the green innovation efficiency rating is greater than 1), and 36.67% of the province's green innovation output is larger than the national average.

3. Study on the Influence Factors of Regional Green Innovation Performance

3.1. Model specification, variables and data

Successful green innovation needs to balance the various driven factors on the innovation chain. This paper analyses the influence factors of regional green innovation performance from three aspects: technology, market and system. The measurement model as follows:

$$\begin{aligned}\ln GIP_{it} = C + \alpha_1 \ln FDI_{it} + \alpha_2 \ln ODI_{it} + \beta_1 \ln IMD_{it} + \beta_2 \ln EMD_{it} \\ + \theta_1 \ln IPS_{it} + \theta_2 \ln MS_{it} + \theta_3 \ln ER_{it} + \theta_4 \ln ER(1)_{it} + \varepsilon_{it}\end{aligned} \quad (1)$$

In this case, the green innovation performance (GIP) is measured above. The FDI and ODI are the technical factor that affects the regional green innovation, while the IMD and EMD are the market factor, and the IPS, MS and ER are the institutional factors. α_i, β_i, θ_i are the coefficient of regression for each factor, C represents the intercept term, ε_{it} indicates the error term of the whole regression equation, and the subscript *i* and t respectively indicate the selected region and year.

Technical factors. The innovation capacity of a country or region is mainly due to internal independent innovation and international technology spillover. Regional green innovation performance, therefore, tend to be internal research and development activities and the influence of external international technology spillovers, but in view of the above evaluation in the process of considering the role of the independent innovation factors such as R&D, this part only consider foreign direct investment, foreign direct investment and the influence of exogenous technological factors. Among them, foreign direct investment (FDI) is measured by its investment(Yang, 2015) [11], which reflects the spillover effect of foreign direct investment in the region. Outward direct investment (ODI) is measured by the foreign direct investment stock inspection, and test the backward spillover effect it obtained.

Market factors. Market demand is the root cause of innovation activities and the final destination of innovation results. Besides, the market demand of green innovation includes domestic market demand and foreign market demand. Thus, we use the average earnings of urban residents to measure our domestic market demand, and to test the impact of regional earnings on the performance of green innovation. Instead, that external market demand (EDM) use industrial export delivery values as a measure of the proportion of industrial output value, reflecting the impact of local export guidance on green innovative performance(Bi et al., 2013) [2].

Institutional factors. Green innovation can produce positive spillovers in both environmental and economic dimensions, leading to a stronger institutional constraint for green innovation activities. The environment system is regarded as the most important influence factors, this paper adopts the "three simultaneity" system of environmental protection investment measure environment (ER) (Fan et al., 2013) [7]; ER(1) variable represents a year lagged environment system, testing whether there exists hysteresis influence in the system of environmental on the performance of green innovation(Li et al., 2014) [12]. In addition, the market system (MS) and the intellectual property protection system (IPS) also have an important influence on the green innovation performance, which is measured by the proportion of assets of industrial state-owned enterprises and the cumulative percentage of patent infringement cases(Yang, 2014) [13], so as to examine the impact of the marketization level of the region and the protection of intellectual property rights on green innovation performance.

Data from 2005-2014 China statistical yearbook of science and technology, the industrial enterprise science and technology activity statistics, China industrial economic statistical yearbook, China statistical yearbook, the China environment yearbook and the state intellectual property office. The green patent data comes from the state intellectual property office, which can be searched by setting the keywords of green patent, and further screening and identification by looking at the patent summary(Li, 2015) [14]. Tibet was excluded due to incomplete data. Thus, we analyse of the provinces, municipalities and autonomous regions, a total of 30.

3.2. Results and findings

Based on the results of the F and the Hausman test, we used the fixed effect model to analyse the green innovation performance factor in the whole sample, the eastern region, and the central region, and we did some empirical analysis of the western region, using the hybrid effect model, and the results were shown as shown in table 1.

Table 1. The table shows the results of regional green innovation performance factors.

Variable	National	East	Central	West
FDI	0.036**	-0.066**	0.076	0.059***
	（2.327）	（-2.265）	（1.304）	（4.519）
ODI	0.021***	0.007	0.064*	0.045***
	（2.973）	（0.569）	（1.948）	（3.628）
IMD	-0.130***	-0.092	-0.326*	-0.120***
	（-3.598）	（-1.423）	（-1.699）	（-5.832）
EMD	-0.044*	-0.129*	-0.058	0.042**
	（-1.939）	（-1.762）	（-0.910）	（2.078）
IPS	-0.230**	0.101	0.153	-0.316***
	（-2.457）	（0.497）	（0.723）	（-2.768）
MS	-0.159**	-0.379***	-0.061	-0.036
	（-2.221）	（-2.665）	（-0.327）	（-0.300）
ER	-0.011	-0.018	-0.033	-0.006
	（-1.246）	（-1.310）	（-0.952）	（-0.235）
ER(1)	0.038***	0.025*	0.08*	0.016
	（4.059）	（1.743）	（1.936）	（0.575）
R^2	0.892	0.830	0.703	0.565
F-test	10.666***	17.473***	6.537***	1.367
H-test	16.006**	22.681***	-	11.710
Model	Fixed	Fixed	Fixed	Hybrid effect model

Dependent variable: GI.
All explanatory variables are measured pre-treatment.
* p < 0.10, ** p < 0.05, *** p < 0.01

Analysis of regression results based on national samples. In view of that regression result, R^2 of the whole sample is 0.892, and the fit effect is good. Firstly, in terms of technical factors, the regression coefficient of foreign direct investment (FDI) and outward direct investment (ODI) is positive, which means that international technology spillover is obtained through FDI and foreign direct investment in China's regional green innovation activities. On the one hand, as the vehicle of finance and technology, the entry of FDI has increased the investment of green innovation in our region, and has helped green innovation in human resources; At the same time, some foreign enterprises use more environment-friendly production technology and pollution treatment technology, which plays a good demonstration role for China's green innovation, and thus has a positive spillover effect on regional green innovation performance. On the other hand, foreign direct investment (especially foreign direct investment with the motivation of acquiring the advanced technology of R&D intensive host country) can form reverse technology spillover through technology cluster absorption mechanism, overseas market competition mechanism, R&D resource sharing mechanism and technology two-way communication mechanism, thus promoting the promotion of green innovation performance. Secondly, in terms of market factors, the regression coefficient of internal market demand (IDM) and external market demand (EDM) is significantly negative, which means that both urban residents' income level and industrial export are negatively correlated with green innovation performance. In terms of the internal market demand (IDM), the environment Kuznets curve suggests that environmental pollution and per capita revenue are in the form of a "U" relationship, with only a critical or "turning point" per person per capita, environmental pollution will be reduced by the increase in per capita incomes, and the environmental quality of the environment is improving. The income level of urban residents is negatively correlated

with the green innovation performance, indicating that our country is still in the left of the inflection point of the environmental Kuznets curve, and the current development model of pure pursuit of quantity growth has led to the lack of attention and even neglect of green innovation in the process of economic development in China. In terms of external market demand (EDM), some export enterprises excessively pursue the expansion of export scale due to lack of sufficient environmental protection awareness, ignoring the environmental impact and resource consumption caused by the export. Driven by the maximization of economic benefits, export enterprises tend to obtain more economic profits at the expense of environmental benefits, and reduce operating costs by reducing or even avoiding the investment of green innovation, which is not conducive to the improvement of green innovation performance. Thirdly, in terms of institutional factors, the regression coefficient of intellectual property protection system (IPS) and market system (MS) is significantly negative, which also has negative influence. In the case of IP protection, the stricter intellectual property protection can effectively prevent "hitchhike" behaviour, increase the initiative of innovative subject green initiatives; At the same time, however, the strict intellectual property protection reduces the possibility of the innovative body to acquire the external advanced green information, and increases the simulation of innovation difficulties and prevents the diffusion of green innovation results. So far, the green innovation in our country is based on imitation of innovation, the ability to innovate autonomously, and strict intellectual property protection has restricted the diffusion of green innovation, and it's bad for the development of green innovation in the region. In view of that market system (MS), the specific gravity of state-owned enterprise reflects the degree of monopoly in the market, and the higher the proportion of the state, the more the monopoly is, the lower the efficiency of the green innovative resource allocation, and the lower the effect of green innovation. In addition, state-owned enterprises are affected by the diversification of targets, which leads to insufficient attention to green innovation activities and insufficient incentive for green innovation. Therefore, the higher the proportion of state-owned enterprises, the less conducive to green innovation activities and the improvement of green innovation performance.

The regression coefficient of the environmental system (ER) is not significant, while the environmental system ER(1) is significantly positive, which means that the environmental system has a positive influence on the one year lagged regional green innovation performance. Compared with the traditional innovation, green innovation can achieve multi-party benefits of economy, society and environment, but the environmental benefits brought by green innovation will be acquired by the society, while the green innovation subject should pay more cost than traditional innovation, which leads to the lack of sufficient innovation incentive for green innovation. Therefore, if no external constraint is applied, the competition between green technology and traditional technology will be distorted, thus reducing the enthusiasm of regional green innovation, which is unfavourable to the improvement of green innovation performance. It is shown that that environmental control strength has significant positive influence on green innovation performance in our country, and the better the green innovation performance in the region with higher environmental control intensity, which supports the "Potter Hypothesis" theory. In order to further compare the regional difference of the above factors influencing on the green innovation performance, a regression estimate is carried out from three sub-samples in the east, central and west.

Firstly, technical factors. Foreign direct investment (FDI) in the eastern region of the green innovation performance has a significant negative influence. This difference mainly lies in the gradual decline of the green innovation ability in the three regions. The green innovation capacity and production technology of most provinces in the eastern region are quite than that of foreign enterprises. It is difficult to obtain the spillover effect of green innovation by means of model imitation effect and association effect. However, the competitive effect caused by foreign enterprises will aggravate the vicious competition among enterprises in the eastern region, which will not be conducive to the improvement of green innovation performance in the region. In the western region, the green innovation ability and production technology environmental protection level are relatively low. In recent years, the transfer of foreign capital to the western region has enabled the region to obtain spillover effects through demonstration imitation and industrial association, and to promote the improvement of green innovation performance. External outward direct investment (ODI) has a

significant positive influence on green innovation performance in the central and western regions, but has no significant impact on the eastern region. The central and western regions can improve the performance of green innovation through the reverse technology spillover of FDI. Secondly, the internal market demand (IDM) has a significant negative impact on the green innovation performance in the central and western regions, and has a more significant impact on the western region, while the impact on the eastern region is not significant. It's a feature that fits the environmental Kuznet curve, which means that income of urban residents of the eastern part pays much more than the central region, and the central region pays more than the west. The external market demand (EDM) has negative influence on the green innovation performance in the eastern region, which has no significant influence on the central region, and has a significant positive influence on the western region. This is mainly because of the central region export-oriented industrial enterprises were significantly higher than those in the western region, and the eastern region export enterprises will lead to the fierce competition between enterprises which are more pursuit of scale expansion with low cost, and decrease the cost of green innovation into further compression. Thirdly, institutional factors. The intellectual property protection system (IPS) has a positive impact on the green innovation performance in the central and eastern regions, but the regression coefficient has not passed the significance test, while in the western region is significantly negative. This is also because of the high green innovation capability in the eastern and eastern regions, while the green innovation capability in the western region is lower. And, the more strict intellectual property protection system reduces the possibility of model innovation in the western region, which is not conducive to the improvement of green innovation performance in the region. The market system (MS) has a significant negative influence on the green innovation in the eastern region, while the negative influence on the central and western parts is not significant. Besides, the green innovation ability in eastern regions is much higher than the other regions, but still needs to build more market-based competitive mechanisms to increase the efficiency of green innovation, so the green innovation is restricted by the state-owned enterprises.
The regression coefficient of the environmental system (ER) was not significant in all three regions. However, the regression coefficient of ER(1) is significantly positive in the central and eastern regions, while the western region is not significant. So the one year lagged environmental regulation has a positive influence on the green innovation performance in the central and eastern regions.

4. Conclusion

In terms of green innovation performance evaluation, the mean value of regional green innovation performance evaluation showed the M type volatility tendency in the whole country in 2005-2014. The green innovation performance evaluation in the eastern region has the highest value, and the central is the same as the national average, and the evaluation value in the western is significantly lower. Therefore, in order to reduce the green innovation performance gap in the eastern and western regions, we need formulating the moderate policy in different regions. Local governments in the central and western regions must increase the local green innovation fund support. Through tax incentives and financial subsidies lead the central and western enterprises to carry out green innovation. To improve the financing system and environment of green innovation, we need to channel more social capital into green innovation investments. At the same time, we should establish a strict system of intellectual property rights protection, protect the excess profits brought by the innovation of green innovation, and avoid the incentive of free riders to reduce the innovation enthusiasm of green innovation subjects.
In terms of influencing factors of the whole nation, foreign direct investment(FDI), outward direct investment(ODI), the one year lagged environmental system has a positive impact on the green innovation performance, while internal and external market demand, the protection of intellectual property rights system, market system has a negative influence on it. From the perspective of the three regions, FDI and external market demand have a negative impact on the green innovation performance in the eastern region, and have a positive influence on the western region. The foreign direct investment has a positive impact on the green innovation performance in the central and western regions. The internal market demand has a negative impact on the green innovation performance in the central and western regions. The intellectual property rights protection system has a negative impact on the green innovation performance in the western region. The market system has a negative impact

on the green innovation performance in the eastern region, and the one year lagged environmental system has a positive influence on the green innovation performance in the central and eastern regions. Therefore, when considering foreign direct investment, outward direct investment, external market demand and other open economic factors, we should focus on the development of east, middle and western regions. In introducing foreign direct investment, we should pay attention to the level of foreign investment in environmental technology, but also pay attention to the leading principle of "sub-region and classification", that is, according to the economic development priorities and development level of the three regions of eastern and western China, we will formulate a catalogue of green technologies that are suitable for the local economic development and absorption capacity, and do a good job in the distribution of echelons in the three regions. In formulating environmental control policies, we should establish a decentralized environmental control model that is more suitable for economic development, and give local standards under the premise of national uniform standards. Improving the market competition mechanism can direct the green shift of market demand. On the one hand, we will continue to deepen the reform of state-owned enterprises, invigorate the market, and improve the allocation of green innovative resources through market mechanisms; On the other hand, the promotion of green consumption concept and education can strengthen the green consumption awareness among enterprises and consumers, and lead and support the social purchase of green products to form a good green consumption pattern.

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