Article

Analysis on Spatio-temporal characteristics and influencing factors of industrial green innovation efficiency——From the perspective of innovation value chain

, Liyuan Zhang [1],Pengzhen Liu [2],* and Heather Tarbert[1]

[1] Department of Business and Creative Industries, University of the West of Scotland, Paisley, Scotland, UK; B00357508@studentmail.uws.ac.uk
[2] School of Management, Shandong University of Science and Technology, Zibo, Shandong,China; 3380049466@qq.com

* Correspondence: 3380049466@qq.com; Tel.: 0044-7512875613

Abstract: Green innovation has become an important combination of high-quality economic growth and sustainable development of ecological environment. In this paper, the super-efficiency network SBM model is used to measure the two-stage green innovation efficiency of industrial science and technology R&D and achievement transformation in 30 provinces and cities from 2009 to 2019, and exploratory Data Analysis (ESDA) and spatial econometric model are used to investigate the spatial-temporal evolution characteristics and influencing factors of green innovation efficiency. The results show that: firstly, the overall efficiency of industrial green innovation is low, and the efficiency of scientific research and development and achievement transformation has experienced three stages of "upward-declining-revitalized period". The low efficiency of achievement transformation is an important factor hiding the improvement of the efficiency of industrial green innovation. Secondly, The industrial green innovation efficiency gradually increases from northwest to southeast, forming a centralized "line" and "block" distribution. The high efficiency area is still concentrated in the eastern coastal region, and the balanced development trend is obvious in the central and western regions. Finally, openness has a positive impact on the two-stage green innovation efficiency; Industrial structure and government investment in science and technology have a positive impact on the efficiency of science and technology research and development, but have no significant effect on the efficiency of achievement transformation. Enterprise size has a positive effect on achievement transformation efficiency, but has no significant effect on R&D efficiency. Environmental regulation has a positive impact on R&D efficiency and a negative impact on achievement transformation efficiency.

Keywords: Industrial green innovation efficiency, Innovation value chain perspective, Super-efficient network SBM model, Spatial Dubin model

1. Introduction

The COVID-19 epidemic has brought great changes to the world. As the baton of green economic development, the new development concept aims to reduce the environmental additional cost of economic growth [1] and promote the transformation of economic development from speed to quality. More importantly, the industrial industry, as the main battlefield of green innovation activities, is the backbone and important gripper of implementing scientific and technological innovation, and plays an important role in promoting efficient and stable economic growth and enhancing comprehensive national strength. However, for a long time, in the development process of green innovation, " borrowlism"[2] and "empiricism" were prevalent. Industry-University-Research is seriously decoupled, the innovation elements

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

are fragmented and patched, and the innovation driving ability is weak. In addition, the problems of unbalanced regional development, low efficiency of scientific and technological achievements transformation, and high additional environmental costs are becoming increasingly prominent, which seriously hinder the development of industrial green innovation to high quality, specialization and deep level [3]. In short, how to effectively promote the coordinated development of industrialization and green innovation is very important. In addition, scientific measurement of industrial green innovation efficiency is a strategic measure to guide economic development from extensive to resource-saving and environment-friendly.

At present, the research on green innovation mainly focuses on the following three aspects. discuss and measure the efficiency of green innovation; study on regional (industry) differences of green innovation efficiency; analysis on Influencing Factors of green innovation efficiency. Although academic research on green innovation has made rich achievements, there are still the following shortcomings. Firstly, most of the existing studies on green innovation efficiency only focus on the overall innovation input-output, and there is little phased analysis of innovation activities. But in fact, the process of green innovation is made up of many sub-processes, such as R&D manufacturing, sales promotion, and product commercialization [4]. Therefore, this paper creatively decomposes green innovation into two stages: R&D of science and technology and achievement transformation, and discusses the life cycle and activity law of different stages respectively. Secondly, most scholars examine the influencing factors of industrial green innovation efficiency from an overall perspective, ignoring that factors such as location resource endowment and corporate density may have different degrees of influence on the industrial green innovation efficiency in two stages, and treating them as a continuous process will hide the influence intensity of different stages on industrial innovation level.

In view of above, based on the perspective of innovation value chain, this paper uses the super efficient network SBM model to calculate the efficiency of two-stage industrial green innovation in 30 provinces and cities in China from 2009 to 2019. At the same time, combined with exploratory spatial data analysis (ESDA) and spatial econometric model to explores the temporal change characteristics and spatial evolution law of industrial green innovation efficiency, and creatively analyzes the action mechanism of various influencing factors on R&D of science and technology and achievement transformation efficiency. In addition, find out the key factors affecting the efficiency of industrial green innovation, and expect to provide targeted suggestions for improving the efficiency of China's industrial green innovation from the perspective of regional coordination

2.Literature review

The concept of green innovation was first put forward by Fussler et al. [5]. They put forward that the coexistence of positive externalities of innovation results and positive externalities of environmental benefits is a typical feature of green innovation. At present, the academic definition of green innovation has not formed a unified conclusion. Starting from the goal orientation [6], some scholars believe that green innovation focuses on saving resources and reducing environmental pollution through scientific and technological research and development and clean energy production technology. From the perspective of product life cycle, some scholars believe that green innovation can effectively reduce the cost of new products, which is reflected in a series of processes from technical concept to product R&D, to sales promotion, and finally to product marketization [7]. Generally speaking, green innovation is an integrated concept. Although different scholars have different definitions of its concept, it is generally believed that any creative behavior that is conducive to the harmonious development of "Economic-Resource-Environment" can be called green innovation.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

At present, the research on green innovation mainly focuses on the following aspects: Firstly, discuss and measure the efficiency of green innovation[8]. For example, Zhang et al. [9] uses stochastic frontier analysis (SFA) to build a three-stage combined efficiency measurement model to calculate the green innovation efficiency of high-tech industries in 28 provinces and cities in China. Xiaoyang [10] discussed the efficiency of green technology innovation in 30 provinces in China through the traditional DEA-BCC model. Feng [11]aimed at the problem that the traditional DEA model ignores the "relaxation" of elements and can not solve the unexpected output, the DEA-SBM model is used to measure the green innovation efficiency of eight economic regions in China, and compared with the traditional CCR model, it is found that the SBM model is more realistic and the conclusion is more scientific. In a word, the super-efficiency DEA model not only solves the problems of slack variables and unpredictable output, but also overcomes the problem of not being able to compare the differences of the same decision-making units, and has been widely used in efficiency measurement. For example, Dong et al. [12] used the super efficiency SBM model considering unexpected output and exploratory spatial data analysis to deeply discuss the spatial evolution characteristics of green innovation efficiency in the Great Bay area of Guangdong, Hong Kong and Macao; Cui Rong et al. [13]used the super efficiency SBM Malmquist index model to calculate the green innovation efficiency of 30 provinces in China from the dual perspective of environmental pollution and innovation quality.

Secondly, research on the regional (industry) differences of green innovation efficiency [14]. The research on green innovation efficiency involves two levels: micro and macro. Micro-fields are mainly enterprises and industries, including tourism [15], manufacturing industry [16], high-tech industry [17], etc. The research focuses on the evaluation of green innovation efficiency to reduce the additional cost of industrial (enterprise) development environment. At the macro level, it is more inclined to regional studies such as provincial [18], urban agglomeration [19] and prefecture-level cities [20], which mainly emphasizing the temporal change, spatial characteristics and regional heterogeneity of green innovation efficiency.

Thirdly, analysis of influencing factors of green innovation efficiency. Green innovation efficiency is affected by both the external environment and internal driving force. From the perspective of external environmental factors, government technical expenditures and degree of openness [21] can significantly improve the efficiency of green innovation; The impact of environmental regulation [22] and industrial structure [23] on the efficiency of green innovation is diversified. From the perspective of internal driving factors, firm scale [24] are conducive to improving the level of green innovation. Although R&D Investment [25] is conducive to improving corporate innovation efficiency, it needs to match with the enterprise scale. Government innovation policy [26] can provide institutional guarantee for enterprises and avoid the risks encountered in the innovation process as much as possible.

3. Research methods and index selection

3.1 Model selection

3.1.1 Super efficient network SBM model

Compared with the traditional DEA model, the super-efficiency network SBM model can explain the internal operation law of the green innovation system, open the "black box" of innovation activities, decompose it into multiple sub-processes and locate the specific source of output inefficiency. In addition, the model modifies the constraints based on input-output angle, which greatly improves the measurement accuracy. Therefore, based on the previous research

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

[27], this paper calculates the two-stage green innovation efficiency through the super-efficiency network SBM model. The specific equations are as follows.

$$\rho_0=\min\frac{\sum_{k=1}^{K} w^k[1+\frac{1}{m_k}\sum_{i=1}^{m_k}\frac{s_i^{k^-}}{x_{i0}^k}]}{\sum_{k=1}^{K} w^k[1-\frac{1}{u_{1k}+u_{1k}}(\sum_{r=1}^{u_{1k}}\frac{s_r^{dk}}{y_{r0}^{dk}}+\sum_{r=1}^{u_{2k}}\frac{s_r^{bk}}{y_{r0}^{bk}})]}$$
$$s.t.\ x_0^k \geq \sum_{j=1,\neq 0}^{n}\lambda_j^k x_j^k + s^{k^-},\ y_0^{dk} \leq \sum_{j=1,\neq 0}^{n}\lambda_j^k x_j^{dk} + s^{dk},$$
$$y_0^{bk} \geq \sum_{j=1,\neq 0}^{n}\lambda_j^b y_j^{bk} - s^{bk},\ \varepsilon \leq 1\text{-}\frac{1}{u_{1k}+u_{1k}}(\sum_{r=1}^{v_{1k}}\frac{s_r^{dk}}{y_{r0}^{dk}}+\sum_{r=1}^{v_{2k}}\frac{s_r^{bk}}{y_{r0}^{bk}}), \tag{1}$$
$$z^{(k,h)}\lambda^h = z^{(k,h)}\lambda^k,\ \sum_{j=1,\neq 0}^{N}\lambda_j^k = \sum_{k=1}^{K} w^k = 1,$$
$$\lambda^k \geq 0, w^k \geq 0, s^{k^-} \geq 0, s^{dk} \geq 0, s^{bk} \geq 0$$

$$\rho_0^1=\frac{1+\frac{1}{m_1}\sum_{i=1}^{m_1}\frac{s_i^{1-}}{x_{i0}^k}}{1-\frac{1}{\psi}\sum_{r=1}^{\psi}\frac{s_r^{1+}}{z_{r0}}},\rho_0^2=\frac{1+\frac{1}{\psi}\sum_{r=1}^{\psi}\frac{s_r^{1+}}{z_{r0}}}{1-\frac{1}{u_{12}+u_{22}}(\sum_{r=1}^{u_{12}}\frac{s_r^d}{y_{r0}^d}+\sum_{r=1}^{u_{22}}\frac{s_r^b}{y_{r0}^b})} \tag{2}$$

Where n stands for 30 provinces and cities of the decision-making unit, m_k, and u_k represent input and output respectively. Ψ_k is the number of intermediate indicators. x_j^k represents the input of stage k. Y^d, Y^b matrices represent expected output and unexpected output respectively. $z_j^{(k,h)}$ represents the intermediate product between node k and node h. λ^k, w^k represents the K-stage model and node weight respectively. s_i^{1-}, s_r^{1+}, s_r^d and s_r^b represents the slack variables of input and output in the first stage and the second stage respectively. u_{12} and u_{22} are the number of expected outputs of the second stage respectively. ρ_0, ρ_0^1 and ρ_0^2 respectively represent the overall effeciency of green innovation, the efficiency value of the first stage and the efficiency value of the second stage.

3.1.2 Kernel density estimation

Kernel density estimation, as a nonparametric estimation method, has the advantage that it does not need the specific form of preset function, thus avoiding the sensitivity to the set model [28]. Auuming that the probability density of continuous random variable x at x_0 is $f(x_0)$,, the specific equation is:

$$f(x)=\frac{1}{Nh}\sum_{i=1}^{N}K(\frac{X_i-x}{h}) \qquad (3)$$

where, N represents the number of research sample, X_i represents the independent identically distributed observations，x is the average value, h is Bandwidth. The function K represents the kernel density function. In this paper, Gaussian kernel function is used to dynamically study the efficiency of industrial green innovation.

3.1.3 Spatial econometric model

Different from traditional regression methods, spatial econometric model can effectively solve the complex problem of spatial dependence. The commonly used models in previous research mainly include spatial autoregressive model (SAR), spatial error model (SEM) and spatial Dubin model (SDM). Because the spatial Dubin model (SDM) considers the spatial correlation of dependent variables and independent variables at the same time, it has stronger explanatory ability Therefore, this paper takes the spatial Dubin model as the starting point of econometric model analysis, and its general form is as follows:

$$\ln Eff_{i,t}=\rho W\ln Eff_{j,t}+\gamma_i WX_{i,t}+\beta_i X_i+\mu_t+\eta_i+\varepsilon_{i,t} \qquad (4)$$

Based on the theoretical model derivation, the empirical model of this paper is:

$$\begin{aligned}\ln Eff_{i,t}&=\rho W\ln Eff_{j,t}+\gamma_1 W\ln ES+\gamma_2 W\ln INS+\gamma_3 W\ln OPEN\\&+\gamma_4 W\ln GOV+\gamma_5 W\ln ER+\beta_1\ln ES+\beta_2\ln INS+\beta_3\ln OPEN\\&+\beta_4\ln GOVE+\beta_5\ln ER+\mu_t+\eta_i+\varepsilon_{i,t}\end{aligned} \qquad (5)$$

In the equition, ρ represents the spatial lag item coefficient, γ_i is the spatial autoregressive coefficient of explanatory variable. μ_t and η_i represents individual fixed effect and time fixed effect respectively. $\varepsilon_{i,t}$ is random interference term.

3.2 Index selection

For variable selection, referring to the research results of Nasierowski [29], green innovation is divided into two stages: technical R&D and achievement transformation. The details are as follows.

Input indicators for phase I. The input factors of green innovation mainly consider both human and capital factors. For the capital input of green innovation, previous research usually uses R&D expenditure to express it. However, this approach ignores the effect of the previous capital stock on innovation results, and fails to reflect the cumulative effect and time-lag effect of capital input on green innovation. Therefore, based on the treatment method of Chen [30], this paper uses the perpetual inventory method to calculate the R&D capital stock of each region. Manpower input is usually expressed by the number of R&D personnel or the full-time equivalent (FTE) of R&D practitioners [31]. Considering

 doi:10.20944/preprints202111.0485.v1

that both the number of labor force and the length of practical work have an impact on green innovation activities, this paper believes that the latter can better represent the level of human input.

Input indicators for phase II include: intermediate output and additional input. Green intermediate output of innovation mainly refers to technical output. This paper selects the total number of patent applications, the number of invention patents and the number of new product development projects to represent technical output. Additional investment includes R&D funds for new products, purchase of domestic technology and total industrial energy consumption. In addition, as an important participant of green innovation activities, industrial enterprises need to consume a lot of energy in the process of green innovation. Therefore, the total industrial energy consumption is selected as additional investment.

The final output indexes mainly include economic output and unexpected output. As for economic output, most of the existing researches adopt economic scale or sales revenue of new products. Considering the overlap of the two data and the fact that the sales revenue of new products can better reflect the profit-making ability of green innovation, the sales revenue of new products is selected as the representative. The characteristics of accidents are industrial SO 2 discharge, industrial wastewater discharge, industrial solid waste discharge and industrial smoke (powder) dust discharge. These four indicators can reflect the direct impact of excessive resource consumption, unreasonable industrial structure and extensive production mode on the environment in the process of innovation. Specific indicators are shown in Table 1.

Table 1. Selection of efficiency index of industrial green innovation

Indicator type	Evaluating indicator	Variable	Unit
Phase I input index	Capital investment	R&D capital stock	10,000 Chinese yuan (RMB)
	human input	Full time equivalent of R&D practitioners	People
Phase II input index	Intermediate outputs	Total patent applications	Piece
		Authorized amount of invention patents	Piece
		Number of new product development projects	Piece
	Additional investment	New product R&D funds	10,000 Chinese yuan (RMB)
		The cost of purchasing domestic technology	10,000 Chinese yuan (RMB)
		Total industrial energy consumption	10000 tons of standard coal
Final output	Economic output	Sales Revenue of New Products	Ten thousand Chinese yuan (RMB)
	Undesirable output	Industrial SO_2 emission	10,000 tons
		Industrial wastewater discharge	10,000 tons
		Discharge of industrial solid waste	10,000 tons
		Industrial smoke (powder) dust emission	10,000 tons

3.3 Data collection

Selected the sample data of 30 provinces (cities and autonomous regions) in China from 2009 to 2019. Considering the availability and authenticity of the data, the sample does not include Tibet Autonomous Region, Hong Kong, Macao and Taiwan. The index data comes from China Statistical Yearbook, China Science and technology statistical yearbook, China Industrial statistical yearbook, China Patent statistical annual report and EPS database over the years. For the missing data of the year, the interpolation method is used to supplement.

4. Temporal and spatial evolution law of industrial green innovation efficiency

4.1 Analysis on time series characteristics of industrial green innovation efficiency

The network DEA-SBM model is used to calculate the R&D efficiency of science and technology, achievement transformation efficiency and total efficiency of industrial green innovation in 30 provinces and cities of China.

The results are shown that (Figure 1): the average total efficiency is in a fluctuating upward trend from 2009 to 2019, but the efficiency values are lower than 0.5, which indicates that although industrial green innovation has been steadily improved, it is still at a low level, and the allocation of innovation resources needs to be further optimized, which has great room for improvement.

There are two main reasons for the steady increase in the efficiency of Industrial Green Innovation: Firstly, China's economy is in the primary stage of gradually changing from the"three high" and "one low" [32] black development model transform into the innovation-driven green development pattern [33], which has increased the space for enterprise innovation activities, increased the initial investment in innovation and development, accelerated the pace of building an innovative country, and a variety of factors jointly drive the improvement of industrial green innovation efficiency. Secondly, under the constraints of ecological civilization construction in recent years, China's economy has gradually transform from "rapid development" to "high-quality development" [34]. The government has increased investment in environmental protection, strengthened environmental pollution control, improved resource utilization efficiency through environmental regulation, improved the green innovation environment of enterprises, and forced enterprises to improve production methods and innovation ability.

It can be seen from Figure 1 that, in terms of stages, the efficiency of scientific and technological research and development and the efficiency of achievement transformation show the evolution trend of "rising-declining-rising". In the stage of scientific and technological research and development, with the deepening understanding of new development concepts, the initial resources such as scientific research funds and human capital are increased. Local governments pay attention to the introduction and cultivation of high-tech talents, and constantly introduce policies conducive to innovation, which have laid a good environment for innovation activities of enterprises, created an efficient and convenient green channel, promoted the efficiency of scientific and technological research and development, and provided preconditions for the output of knowledge achievements. In the stage of achievement transformation, the efficiency of achievement transformation is far lower than that of scientific and technological research and development. The reason is that, on the one hand, China's market of scientific and technological achievements is still in its infancy, the absorption and transformation ability of innovation achievements is relatively weak, and the market service system is imperfect and the resource ratio is unreasonable. The excessive emphasis on the economic benefits brought by achievement transformation leads to the problems of input redundancy and output inefficiency, which leads to low marketization efficiency in the stage of achievement transformation. On the other hand, the efficiency of achievement transformation depends on the efficiency of scientific and technological research and development. Because of the long

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

research period, slow effectiveness and certain lag in the stage of scientific and technological research and development, and the slight increase of knowledge achievements, such as papers, works and appearance patents, etc., the efficiency of achievement transformation is low. Therefore, improving the market transformation efficiency of scientific and technological achievements becomes the key to improve the efficiency of industrial green innovation.

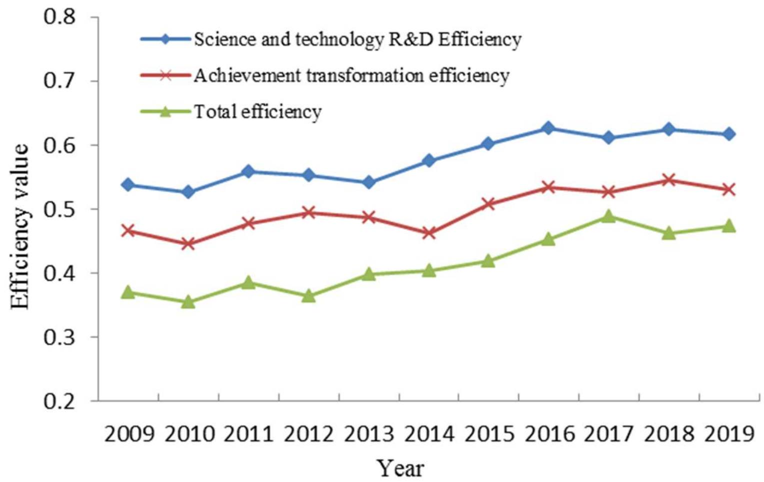
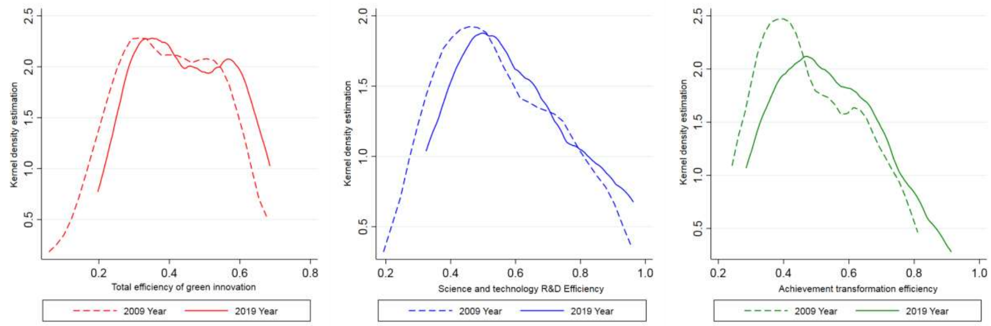


Figure 1. Average change trend of industrial green innovation efficiency

In order to further reveal the dynamic evolution characteristics of green innovation efficiency in two stages of industry, the kernel density estimation method is used to investigate the changes of efficiency curve distribution and peak shape, as shown in Figure 2. During the research period, the core density curves of the total efficiency of industrial green innovation, the efficiency of scientific research and development and the efficiency of achievement transformation gradually moved to the right with the passage of time, but the moving range was small, and the left skewness distribution of each curve was basically the same. This phenomenon indicated that the efficiency showed an increasing trend as a whole, but it was still dominated by low efficiency areas. From the peak shape, the total efficiency of green innovation has gradually formed a pattern of "one master and one time", with the curve on the right side of 0.8 increasing, the overall development trend is good, and the pattern of "polarization" has gradually become prominent. The peak value of achievement transformation efficiency decreased obviously, the peak value degenerated into a broad peak, the regional differences narrowed, and the high efficiency areas increased. In this regard, inter-regional exchanges and cooperation should be strengthened to form the "technology catch-up" effect in low-efficiency areas and promote the transformation and upgrading of industrial structure.



Fugure2. kernel density curve of industrial green innovation efficiency

4.2Analysis on spatial characteristics of industrial green innovation efficiency

With the help of ArcGIS 10.2 software, draw the spatial distribution map of industrial green innovation efficiency in 2009 and 2019, as shown in Figure 3. At the same time, the total innovation efficiency, scientific and technological R&D efficiency and achievement transformation efficiency are divided into four levels by using the natural discontinuity method. From low to high, they are low efficiency area, low efficiency area, high efficiency area and high efficiency area.

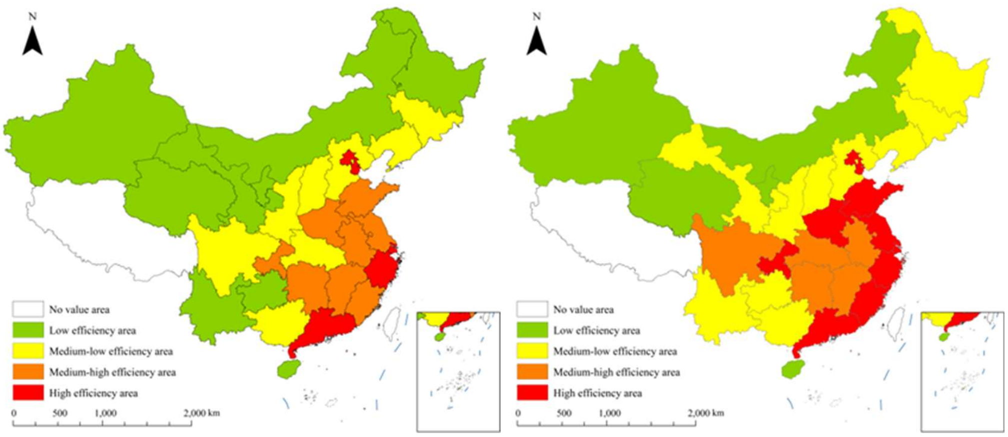
In terms of the overall efficiency of green innovation, Beijing, Tianjin, Zhejiang, Guangdong and Shanghai were always located in the high efficiency zone during the investigation period. Compared with 2009, Shandong, Henan, Anhui, Jiangsu, Fujian, Sichuan and other provinces joined the high efficiency zone, and Yunnan, Guizhou, Gansu, Heilongjiang and other provinces withdrew from the low efficiency zone. The relative changes of the provinces in the medium-low efficiency zone and the medium-high efficiency zone were relatively stable, accounting for about 60%.

From the spatial distribution pattern, it can be seen that the industrial green innovation efficiency showed a distribution law of gradual increase from northwest to Southeast in 2009. Among them, the high efficiency areas are mainly distributed in the southeast coast (Shanghai, Zhejiang, Guangdong) and Beijing Tianjin Hebei region, the medium-high efficiency areas are mostly concentrated in North China (Shandong, Anhui, etc.) and South China (Hunan, Jiangxi, etc.), the low efficiency areas are mainly distributed in the chain of "Ji Ji Ji Shan Chuan", and the medium-low efficiency areas are concentrated in the northwest connecting areas (Xinjiang, Mongolia, Gansu, etc.) and southwest regions (Yunnan, Guizhou). In 2019, the "ladder" feature of the spatial distribution of industrial green innovation efficiency is further highlighted, which is manifested in the centralized and continuous "linear" and "regional block" distribution. The difference is most significant in the southwest. The high-efficiency areas are still concentrated in the coastal areas, the scope of lower efficiency areas is further expanded, and a high-efficiency "uplift area" is formed in Beijing, Tianjin and Sichuan.

It can be seen from Figure 3 that the high-efficiency areas have expanded greatly, mainly distributed along the Bohai Sea, the East China Sea, the South China Sea and the Yangtze River Basin (Shandong, Jiangsu, Zhejiang, Guangdong, Chongqing, etc.), the high-efficiency areas and low-efficiency areas are mainly distributed in the Northeast (HEI, Ji, Liao), North China (Ji, Jin, etc.), South China (Hunan, Jiangxi, etc.) and Southwest (Yunnan, Guizhou, etc.), and the low-efficiency areas are gradually decreasing, Heilongjiang Gansu and other provinces withdrew from the low efficiency level. In a word, from 2009 to 2019, the overall level of industrial green innovation efficiency has improved, the development of the eastern region has increased steadily, and the central and western regions have gradually developed

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

towards balance and efficiency. The polarization evolution pattern of China's provincial green innovation efficiency needs to be improved.



(a)2009 Year (b) 2019 Year

Figure 3. Spatial Distribution Pattern of Total Efficiency of Industrial Green Innovation

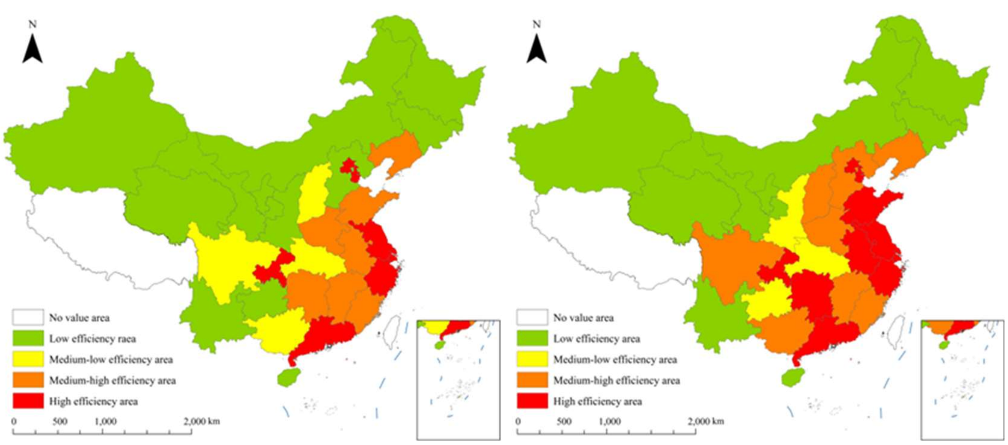
As shown in Figure 4 and Figure 5, by stages, the two-stage green innovation efficiency of seven provinces (cities) such as Beijing, Shanghai, Sichuan and Zhejiang is in the high-efficiency zone, mainly because they have superior geographical location, strong economic foundation, developed private economy and preferential national policies, and use local advantages to gather a large number of high-tech industries and high-tech talents, It provides preconditions for efficient green innovation. For example, the first online technology market established in Zhejiang Province has built a bridge for the transformation of scientific and technological achievements. It has become a "depression" for the transaction of the latest technological achievements and technological needs in Zhejiang Province and even the whole country; After 2008, Chongqing has introduced a large number of leading electronic information enterprises such as Foxconn and HP, which has become an important support and foothold for the industrial transfer in the West. The efficiency of scientific and technological R& D and achievement transformation in Shandong, Anhui and Hunan provinces has improved rapidly, and they will join the high efficiency zone by 2019. These three provinces have large investment in basic research R&D funds and are important R&D bases and knowledge condensing places in China. The innovation efficiency of North China (Henan, Hebei, Shanxi, etc.) and South China (Hubei, Jiangxi, Fujian, etc.) has been improved to varying degrees, mainly concentrated in high-efficiency areas and high-efficiency areas. The main reason is that these provinces are adjacent to the eastern coastal areas or located along the two major watersheds, with a high level of economic development, relatively abundant innovation resources and large room for improvement. However, the change range of scientific and technological innovation in Northeast (Hei, Ji) and Northwest (Xinjiang, Qing, Gan and Ning) areas is small, and they are still in the low efficiency area; However, the transformation efficiency of their achievements increased rapidly, and they all entered the low efficiency area. Yunnan, Hainan and Inner Mongolia are all in low efficiency areas. Affected by geographical location, economic conditions, talent guarantee and other factors, these provinces have unbalanced input-output of scientific and technological innovation and uncoordinated connection between the two stages of innovation, resulting in weak innovation ability and achievement transformation ability, thus inhibiting the improvement of industrial scientific and technological R& D and achievement transformation efficiency.

From the spatial distribution pattern, it can be seen that the efficiency of scientific and technological R&D and achievement transformation in the eastern region is at the leading level. This is because the industry and high-tech industry in the eastern region started earlier and developed rapidly, the investment of initial innovation resources such as human capital is sufficient, the advantages of economic scale and innovation environment are significant, and relying on the advantages of natural location to attract foreign investment, Learning from foreign advanced technology level and management experience, it took the lead in becoming the key promotion area and leading area of domestic green innovation development strategy. In addition, policy support further enhanced the green innovation advantages of the eastern region.

From the spatial distribution pattern, it can be seen that the efficiency of scientific and technological R&D and achievement transformation in the eastern region is at the leading level. This is because the industry and high-tech industry in the eastern region started earlier and developed rapidly, the investment of initial innovation resources such as human capital is sufficient, the advantages of economic scale and innovation environment are significant, and relying on the advantages of natural location to attract foreign investment, Learning from foreign advanced technology level and management experience, it took the lead in becoming the key promotion area and leading area of domestic green innovation development strategy. In addition, policy support further enhanced the green innovation advantages of the eastern region.

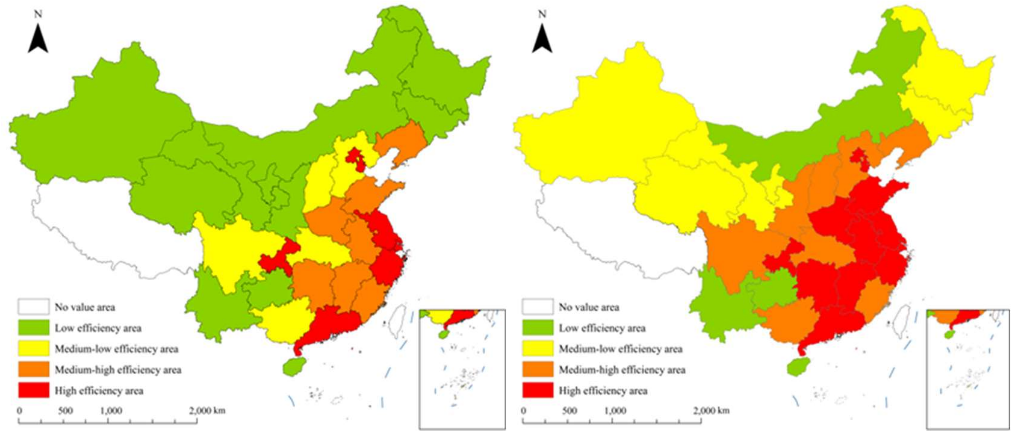
However, the efficiency of scientific and technological R&D in the western region has increased slowly and changed slightly, but the efficiency of achievement transformation has increased rapidly, which is basically consistent with the national average growth level. This is mainly due to the efficient utilization of innovative resources in Sichuan, Chongqing and other places, providing scientific and technological talent guarantee for enterprises, and further broadening the achievement transformation platform with the support of the western development policy, So that scientific and technological achievements can fully create economic value.

Figure 4 Spatial distribution pattern of R&D Efficiency



(a) 2009 Year (b) 2019 Year

Figure 5. Spatial distribution pattern of achievement transformation efficiency



(a) 2009 Year (b) 2019 Year

5. Analysis on Influencing Factors of industrial green innovation efficiency

5.1 Index selection of influencing factors

The influencing factors of China's industrial green innovation efficiency are complex and diverse. Most scholars use traditional measurement methods such as least squares regression and Tobit model to discuss from the aspects of government support and education level. The research process often ignores the spatial heterogeneity of samples. Based on the existing research results [35], this paper comprehensively investigates the industrial distribution characteristics and development status, enriches and improves the influencing factors of industrial green innovation efficiency, and constructs the influencing factor index system from five aspects: enterprise scale, opening-up level, industrial structure, government science and technology expenditure and environmental regulation.

Enterprise scale (*ES*). There are two main viewpoints on the relationship between enterprise scale and Industrial Green Innovation: one is that enterprise scale determines its ability to obtain economy. The larger the scale is, the more conducive it is to green innovation, and there is a positive correlation between them [36]. Another view is that large-scale enterprises will lead to problems such as multiple management levels, solidified operation system and strong resource dependence, which hinder the improvement of green innovation efficiency. Select the industrial GDP / number of enterprises of each province and city to represent the enterprise scale.

Degree of opening to the outside world (*OPEN*). Opening to the outside world influences green innovation through technological knowledge and foreign investment spillover. Scholars generally believe that the stronger the ability of absorbing capital and technology in areas with high degree of opening to the outside world, the easier it is to stimulate the innovation vitality of enterprises. Therefore, this paper selects the total import and export volume to express the degree of opening to the outside world.

Industrial structure (*INS*). Industrial structure is closely related to the unexpected output in the green innovation system, and it is an important factor to realize the sustainable development of green innovation. This paper expresses the industrial structure by the proportion of the added value of the secondary industry.

Government science and technology expenditure (*GOV*). Government science and technology expenditure can promote the efficiency of green innovation within an appropriate threshold, but excessive government support will reduce the innovation enthusiasm of local enterprises, cause enterprises to rely on government finance and hinder the process

 doi:10.20944/preprints202111.0485.v1

of enterprise innovation. In short, the impact of government support is the result of the game between positive and negative externalities.

Environmental regulation (*ER*). Environmental regulation is a "double-edged sword" for the green innovation system. Appropriate regulation can significantly reduce the emission of industrial "three wastes" and reduce unexpected output. Excessive environmental regulation will lead to the "follow cost theory", that is, government environmental regulation makes enterprises need to pay certain environmental treatment expenses in the production process, In order to make up for this part of the cost, enterprises will increase energy input to obtain high output, resulting in an increase in the emission of environmental pollutants. In this paper, the investment in industrial pollution control is used to characterize environmental regulation, and the specific indicators are shown in Table 2.

Table 2. Influencing factors of industrial green innovation efficiency

Variables	Index	Variable code	Unit
Enterprise scale	Industrial GDP / number of enterprises	ES	10000 yuan / piece
Degree of opening to the outside world	total imports and exports	OPEN	Ten thousand dollars
Industrial structure	Added value of secondary industry / Total GDP	INS	%
Government science and technology expenditure	Government science and technology expenditure / Total GDP	GOV	%
Environmental regulation	Investment in industrial pollution control	ER	Ten thousand Chinese yuan (RMB)

5.2 Spatial econometric model estimation results

Tobler's First Law of Geography (TFL) of geographic holds that things or attributes are spatially related to each other, with agglomeration, random and regular distribution [37]. If the spatial correlation of the research object is ignored, the prediction results will be biased. Before spatial econometric regression, this paper uses Moran index (supplementary references) to test the spatial correlation of industrial green innovation efficiency based on adjacency weight matrix. The results are shown in Table 3. During the study period, the Moran index of the total efficiency of industrial green innovation was positive and passed the significance test at the 10% level, indicating that the efficiency of industrial green innovation was spatially dependent between different regions. The index value showed a fluctuating upward trend from 2009 to 2019, always floating in the range of [0.135,0.251], and the spatial impact of industrial green innovation efficiency continued to output. In terms of stages, the Moran index of scientific and technological R&D efficiency is positive and significant at the level of 5%. The possible reason is that the scientific and technological R&D stage is mainly the investment of initial resources such as research funds and technicians, and the frequent flow of production factors such as labor and capital among regions, which enhances the exchange and cooperation of enterprises in different regions. In addition, scientific and technological innovation achievements are mainly based on papers, patents Monographs and other explicit knowledge are dominant, which is easy to be absorbed and utilized by innovation subjects. Relying on knowledge and technology spillover, the spatial spillover effect of scientific and technological R&D efficiency is significant. The Moran index of achievement transformation efficiency is positive, but some years fail to pass the significance test. Because the achievement transformation stage mainly involves commercialization activities such as promotion, sales and market segmentation of new products, the spillover of achievement transformation efficiency is restrained based on market competition and privacy protection.

Table 3. Overall efficiency of industrial green innovation and Two stage Moran's I

Year	Total efficiency			Science and technology R&D Efficiency			Achievement transformation efficiency		
	Moran's I	Z value	P value	Moran's I	Z value	P value	Moran's I	Z value	P value
2009	0.135***	2.551	0.001	0.155***	2.954	0.003	0.088	1.125	0.156
2010	0.154**	2.083	0.014	0.176***	2.887	0.003	0.155**	1.479	0.035
2011	0.147*	1.654	0.055	0.194***	2.542	0.000	0.124**	1.275	0.025
2012	0.219**	1.662	0.035	0.225***	2.114	0.000	0.097*	1.552	0.075
2013	0.176*	1.445	0.075	0.216**	1.844	0.017	0.105**	1.758	0.034
2014	0.251***	2.668	0.001	0.207**	2.439	0.011	0.133	1.874	0.185
2015	0.168***	2.105	0.001	0.258***	2.977	0.000	0.154**	2.033	0.044
2016	0.227**	1.857	0.025	0.244***	3.012	0.001	0.127	1.776	0.274
2017	0.215***	2.761	0.000	0.269***	3.174	0.000	0.144*	1.836	0.077
2018	0.226***	1.795	0.000	0.231***	2.785	0.000	0.166**	2.105	0.021
2019	0.238***	2.223	0.001	0.285***	2.655	0.000	0.183**	2.154	0.030

Notes: *,** and *** Denote statistical significance at the 10%, 5% and 1% levels, respectively. The t values are in parentheses.

Stata16.0 software is used to conduct spatial econometric regression on the influencing factors of green innovation efficiency in 30 provinces and cities in China. The Hausman test results reject the original hypothesis at the 5% significant level, so the fixed effect model is selected. Considering the heterogeneity of geographical location and economic development level in the research sample, the spatio-temporal double fixed effect model is selected. The specific results are shown in Table 4. Combined with Ansenlin judgment criterion, through the comparison of corrected R^2 and Log-likelihood estimation results, spatial Dubin model (SDM) is selected for further analysis.

Because green innovation activities include two stages of scientific and technological R&D and achievement transformation, in order to avoid repeated discussion, this paper focuses on the regression results of various influencing factors on scientific and technological R&D efficiency and achievement transformation efficiency.

5.2.1Technology R&D stage

It can be seen from table 3， from the empirical results of science and technology R&D stage, the influencing factors have the following three characteristics. Firstly, geographical proximity has a significant positive impact on science and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

technology R&D efficiency. Correlation coefficients of spatial Dobbin model (SDM) and spatial error model (SEM) ϱ 0.241 and 0.207, respectively, in the spatial lag model (SAR) λ The value is 0.135, and all pass the significance test at the 1% level. The spatial lag coefficient of openness, industrial structure and environmental regulation all pass the test at the 5% level, which indicates that the scientific and technological R&D efficiency of a province and city will be affected by the surrounding areas, and there is an obvious regional correlation effect in space.

Secondly, openness, industrial structure, government science and technology expenditure and environmental regulation have a significant positive impact on science and technology R&D efficiency. It can be seen from table 3 that the regression coefficient of openness is 0.322, which is significant at the level of 5%, and the coefficient is the largest among all influencing factors, indicating that the higher the degree of openness, the greater the regional tolerance and the more opportunities to communicate with foreign businessmen, so as to form regional cultural diversity, promote the emergence of innovative ideas and technology exchange and interaction, and improve the efficiency of scientific and technological R&D. The regression coefficient of industrial structure is 0.106, which is significant at the level of 1%, indicating that industrial agglomeration and the expansion of the number of enterprises have a significant positive impact on science and technology R&D. industrial enterprises have had economies of scale in the R&D process, and the industrial structure has gradually changed to advanced, rationalized and green, reducing environmental pollution and improving the utilization rate of local resources and the efficiency of science and technology R D. The regression coefficient of government science and technology expenditure is 0.097, which is significant at the level of 1%, which fully shows that government support is the basic guarantee for enterprises to realize green innovation. Government science and technology expenditure enhances the innovation enthusiasm of small and medium-sized enterprises to a certain extent, alleviates the shortage of funds in the R&D process, reduces the innovation risk of enterprises and improves the efficiency of scientific and technological innovation. The regression coefficient of environmental regulation is 0.144, which is significant at the level of 1%. This result is consistent with the inference of "Porter Hypothesis", indicating that environmental regulation can effectively promote the efficiency of scientific and technological research and development [38]. The government forces enterprises to carry out independent innovation through incentive and command regulation means, so as to improve the internal production efficiency and technical level of enterprises, and then produce "innovation compensation" for the cost of environmental compliance effect.

Thirdly, the regression coefficient of enterprise scale on science and technology R&D efficiency is negative but not significant. This conclusion is similar to the research results of Yu [39], which may be because the science and technology R&D process has high requirements for innovation environment and diversified system. Compared with small and micro enterprises, large enterprises have complex levels, rigid operation modes and lack of innovation flexibility.

5.2.2 Achievement transformation stage

From the empirical results of achievement transformation stage, the influencing factors of achievement transformation efficiency have the following four characteristics: firstly, geographical proximity has a significant positive impact on achievement transformation efficiency. It can be seen from table 4 that the spatial correlation coefficients are 0.037, 0.145 and 0.187 respectively, which pass the significance test, but the spatial dependence is weaker than that in the scientific and technological R&D stage, which is consistent with the results of spatial autocorrelation test. In addition, the spatial lag coefficient of enterprise scale and openness is significant at the level of 10%.

Secondly, enterprise scale and openness have a significant positive impact on the efficiency of achievement transformation. The regression coefficient of enterprise scale is 0.151, which is significant at the level of 5%. The difference from the scientific and technological R&D stage is that in the achievement transformation, if the enterprise scale is small,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

it is easy to lead to the rupture of capital chain and the termination of production and operation activities, while large-scale enterprises have the ability to invest a lot of manpower and capital to promote the commercialization and marketization of technical products. It can be seen from table 4 that the regression coefficient of the degree of opening to the outside world is 0.318, which is significant at the level of 1%. The possible reason is that opening to the outside world is conducive to product upgrading, promoting enterprise technical exchange and cooperation and market competition. In order to seize the market opportunity, enterprises will continue to enhance their self innovation ability to carry out technological innovation, thus improving the innovation level and achievement conversion rate.

Thirdly, it can be seen from table 4 that the regression coefficient of industrial structure and government science and technology expenditure on achievement transformation efficiency is 0.217, but it is not significant. The main reason is that industries in different regions focus on learning advanced management experience and technical knowledge exchange, have less contact with product R&D and transformation and market competition, and new product achievements rely more on the enterprise's own production plan and marketization experience, and the industrial structure fails to effectively promote the efficiency of achievement transformation. Government science and technology expenditure is mainly to improve the independent innovation ability of enterprises. The financial support obtained by enterprises is mostly used in the scientific and technological R&D stage, and the achievement transformation stage is less affected.

Fourthly, it can be seen from table 4 that the regression coefficient of environmental regulation is -0.114, which is significant at the level of 1%. The main reason is that China's economy is in the initial stage of transforming from extensive growth to high-quality development, the absorption and transformation capacity of innovative resources is relatively weak, and the enhancement of environmental regulation means leads to the closure of some enterprises with high pollution, high consumption and serious waste of resources, In addition, the R&D stage of science and technology has the characteristics of long R&D cycle and slow results, and the knowledge condensation based on patents, monographs and papers has little impact. In the long run, environmental regulation can effectively stimulate scientific and technological R&D, which is an important guarantee for the prominent benefits of later application research.

Table 4. Regression results of two-stage green innovation efficiency

Variables	Science and technology R&D Efficiency				Achievement transformation efficiency			
	OLS	SAR	SEM	SDM	OLS	SAR	SEM	SDM
lnES	-0.035*	-0.131	-0.041	-0.128	0.277*	0.182**	0.107**	0.151**
lnOPEN	0.396**	0.277***	0.286**	0.322***	0.303***	0.411***	0.274***	0.318***
lnINS	0.057***	0.077**	0.106***	0.063***	0.154	0.135	0.118	0.217
lnGOV	0.085***	0.121***	0.097***	0.141***	0.124*	0.088	0.115	0.136
lnER	0.158***	0.141***	0.131***	0.144***	-0.065**	-0.117***	-0.104***	-0.114***
*lnES*W*				0.215				-2.04**
*lnOPEN*W*				0.211**				0.234***
*lnINS*W*				0.041***				0.146
*lnGOV*W*				0.124				0.159
*lnER*W*				0.087**				0.102
λ/ρ		0.135***	0.207***	0.241***		0.037*	0.145***	0.187***

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

R^2-ad	0.701	0.677	0.715	0.737	0.651	0.635	0.688	0.704
Log-likelihood		215.225	227.326	248.542		210.235	214.568	227.305
Individual effect	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time effect	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
N	330	330	330	330	330	330	330	330

Notes: *,** and *** Denote statistical significance at the 10%, 5% and 1% levels, respectively. The t values are in parentheses.

6. Discussion and Conclusions

Based on the perspective of innovation value chain and new development concept, the industrial green innovation efficiency of 30 provinces and cities in China from 2009 to 2019 was calculated by using the super-efficiency network SBM model, and the spatio-temporal evolution characteristics and influencing factors of industrial green innovation efficiency were analyzed by combining exploratory spatial data analysis (ESDA) and spatial multi-objective model.

The research results are as follows: Firstly, during the research period, the total efficiency of industrial green innovation showed a fluctuating upward trend. The efficiency of research and development of science and technology and the efficiency of transformation of scientific and technological achievements have experienced three stages, namely, "rising period, declining period and revitalization period". The average level of the three efficiency values is low, and the low efficiency of transformation of scientific and technological achievement is the main reason that affects the improvement of industrial green innovation efficiency; The kernel density estimation curves are shifted to the right, and the distribution of the left skewness of each curve is basically the same, and the overall development trend is good.

Secondly, the total efficiency of industrial green innovation presents a distribution law of gradual increase from northwest to Southeast, forming a concentrated and continuous "linear" and "regional block" distribution. The high-efficiency areas are still concentrated in the coastal areas, and the balanced development trend of the central and western regions is obvious; In terms of stages, the efficiency of scientific and technological R&D and achievement transformation in the eastern region is at the leading level, the efficiency value of the two stages in the central region is gradually closer to the East, and the growth of scientific and technological R&D efficiency in the western region is gentle, but the growth of achievement transformation efficiency is rapid, which is basically consistent with the national average growth level.

Thirdly, in the stage of scientific and technological research and development, openness, industrial structure and environmental regulation have a significant positive effects on the efficiency of scientific and technological research and development; It has a significant positive impact on the efficiency of environmental science and technology research and development, but the spatial spillover effect is not significant; The scale of enterprises has no significant influence on the efficiency of local and surrounding scientific and technological research and development. In the stage of achievement transformation, the scale and openness of enterprises have a significant positive impact on the efficiency of achievement transformation and spatial spillover effect. Industrial structure and government expenditure on science and technology have no significant impact on the efficiency of achievement transformation, while environmental regulation have significant negative impact on the efficiency of achievement transformation, and the spatial spillover effect is not significant.

According to the above research results, the following practical significance can be drawn: First, enhance the awareness of green innovation, optimize the top ten linkage innovation environment of "Industry-University-Research Gold, Talent, Government and Cloud", intensify the reform of the science and technology system, improve the market mechanism and technological innovation governance system, encourage enterprises to innovate independently, create a good innovation environment, and promote the integrated and efficient allocation of research posts, talent funds and achievements; Improve the organization and management of major scientific and technological innovation projects, implement the "leading" system, and expand the R&D autonomy of universities and scientific research institutions; Establish and improve the mechanism of government investment in scientific and technological innovation and social multi-channel, ensure the sustained and stable basic frontier research, and create a social atmosphere of innovation, entrepreneurship, innovation and fault tolerance among the masses.

Secondly, developing new industries and promoting cooperation among enterprises. Optimize emerging industries and future industries, give full play to the leading role of large enterprises, speed up the cultivation of more "specialized, new and special" enterprises, support the development of start-ups, and vigorously cultivate a number of industries such as information technology, environmental protection and new materials; Strengthen exchanges and cooperation among enterprises by building science cities and science parks, learn from each other's advanced management experience and technology, support enterprises to establish innovation platforms and intellectual property protection alliances, and enhance the transformation ability of scientific research results.

Thirdly, give play to regional advantages and enhance innovation spillover. The belt and road initiative, Guangdong, Hong Kong and Macao, the Yangtze River Delta and other regions should be encouraged to focus on developing green areas, focusing on green development and building city, connecting with the national innovation and empowerment, and promoting interconnection of new infrastructure. There is a good foundation for innovation in the eastern region. While further improving the level of innovation, it is necessary to increase support for the central and western regions and give full play to the role of innovation spillover and "locomotive". The central region should increase investment in scientific and technological innovation, strive for the landing of major scientific and technological projects and national laboratories, attract high-level universities and innovative enterprises, improve the access mechanism for enterprises with high pollution and energy consumption, and raise the entry threshold; The western region should fully absorb the spilled knowledge and technology, actively introduce high-tech talents relying on national policy dividends, speed up the cultivation of innovative forces, improve the market trading environment and promote the transformation of achievements.

Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Funding This research was funded by National Social Science Foundation, grant number 19BJY085.

Declarations

Ethical approval Study did not use any data which need approcal.

Consent to participate All authors participated in the process of draft completion. All authors have read and agreed to the published version of the manuscript.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

Consent to publish All authors agree to publish.

Conflicts of Interest The authors declare no conflict of interest.

Authors' Contributions This paper is a collaborative work of the all the authors. Writing Original Draft Preparation, Visualization and Methodology Pengzhen Liu; Formal Analysis, Funding Acquisition, Writing-Review, Supervision Liyuan Zhang; Data Curation, projection Administration Prof. Heather Tarbert. All authors have read and agreed to the published version of the manuscript.

Ethical approval and consent to participate The authors declare that they have no known competing financial interests or personal relationships that seem to affect the work reported in this article. We declare that we have no human participants, human data, or human tissues.

References

1. Renjie, Zhang, and Dong Huizhong. "Temporal and Spatial Evolution and Influencing Factors of China's Industrial Ecological Efficiency Based on Provincial Scale." *Economic Geography* 7 (2020).
2. Duan, Yunlong, Shuling Liu, Hao Cheng, Tachia Chin, and Xuan Luo. "The Moderating Effect of Absorptive Capacity on Transnational Knowledge Spillover and the Innovation Quality of High-Tech Industries in Host Countries: Evidence from the Chinese Manufacturing Industry." *International Journal of Production Economics* 233 (2021): 108019.
3. Xia, CAO, and YU Juan. "Regional Innovation Efficiency in China from the Green Low-Carbon Perspective." *China population, resources and environment* 25, no. 5 (2015): 10-19.
4. Camisón, César, and Vicente M Monfort-Mir. "Measuring Innovation in Tourism from the Schumpeterian and the Dynamic-Capabilities Perspectives." *Tourism management* 33, no. 4 (2012): 776-89.
5. Fussler, Claude, and Peter James. *Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability*: Financial Times/Prentice Hall, 1996.
6. Mirata, Murat, and Tareq Emtairah. "Industrial Symbiosis Networks and the Contribution to Environmental Innovation: The Case of the Landskrona Industrial Symbiosis Programme." *Journal of Cleaner Production* 13, no. 10-11 (2005): 993-1002.
7. Tariq, Adeel, Yuosre F Badir, Umar Safdar, Waqas Tariq, and Kamal Badar. "Linking Firms' Life Cycle, Capabilities, and Green Innovation." *Journal of Manufacturing Technology Management* (2019).
8. Liu, Chunyang, Xingyu Gao, Wanli Ma, and Xiangtuo Chen. "Research on Regional Differences and Influencing Factors of Green Technology Innovation Efficiency of China's High-Tech Industry." *Journal of computational and applied mathematics* 369 (2020): 112597.
9. Zhang, Feng, Shijia, Ren, and Xiuqing, Yin. "High-Tech Industry Green Technology Innovation Efficiency and Its Scale Quality Threshold Effect." *Science & Technology Progress and Policy* 37, no. 07 (2020): 59-68.
10. Jia, Xiaoyang, and Lin, Sheng. "A Factor Market Distortion Research Based on Enterprise Innovation Efficiency of Economic Kinetic Energy Conversion." *Sustainable Energy Technologies and Assessments* 44 (2021): 101021.
11. Feng, Zhijun. "Research on Industrial Enterprises' Green Innovation Efficiency in China———Based on Provincial Data by a Dea-Sbm Approach." *Forum on Science and Technology in China*, no. 02 (2013): 82-88.

12. Dong, Huizhong, Xuan Li, and Renjie Zhang. "Analysis on Temporal and Spatial Characteristics and Driving Factors of Green Innovation Efficiency in Dawan District, Guangdong, Hong Kong and Macao." *Economic Geography* 41, no. 05 (2021): 134-44.

13. Cui, Rong, Jinhua Fei, and Yanan Sun. "Research on the Change of Green Innovation Productivity and Its Spatial Spillover Effect among Provinces in China." *Macroeconomics*, no. 06 (2019): 132-45.

14. Luo, Xiao, and Weiye Zhang. "Green Innovation Efficiency: A Threshold Effect of Research and Development." *Clean Technologies and Environmental Policy* 23, no. 1 (2021): 285-98.

15. Gürlek, Mert, and Mehmet Ali Koseoglu. "Green Innovation Research in the Field of Hospitality and Tourism: The Construct, Antecedents, Consequences, and Future Outlook." *The Service Industries Journal* (2021): 1-33.

16. Feng, Zhijun, Bo Zeng, and Qian Ming. "Environmental Regulation, Two-Way Foreign Direct Investment, and Green Innovation Efficiency in China's Manufacturing Industry." *International journal of environmental research and public health* 15, no. 10 (2018): 2292.

17. Mills, Ebenezer Fiifi Emire Atta, Kailin Zeng, Liu Fangbiao, and Li Fangyan. "Modeling Innovation Efficiency, Its Micro-Level Drivers, and Its Impact on Stock Returns." *Chaos, Solitons & Fractals* 152 (2021): 111303.

18. Jiang, Zhujun, Pinjie Lyu, Liang Ye, and Yang wenqian Zhou. "Green Innovation Transformation, Economic Sustainability and Energy Consumption During China's New Normal Stage." *Journal of Cleaner Production* 273 (2020): 123044.

19. Huang, Yue, and Yebin Wang. "How Does High-Speed Railway Affect Green Innovation Efficiency? A Perspective of Innovation Factor Mobility." *Journal of Cleaner Production* 265 (2020): 121623.

20. Li, Jing, and YuanXin Du. "Spatial Effect of Environmental Regulation on Green Innovation Efficiency: Evidence from Prefectural-Level Cities in China." *Journal of Cleaner Production* 286 (2021): 125032.

21. xiao, Renqiao, Ying Song, and Li Qian. "Research on Spatial Spillover Effect of Enterprises' Green Innovation Output from the Perspective of Value Chain in Two Stages." *Finance and Trade Research* 30, no. 04 (2019): 71-83.

22. Fei, Fan, Lian Huan, Liu Xiaoyang, and Wang Xueli. "Can Environmental Regulation Promote Urban Green Innovation Efficiency? An Empirical Study Based on Chinese Cities." *Journal of Cleaner Production* 287 (2021): 125060.

23. Du, Kerui, Yuanyuan Cheng, and Xin Yao. "Environmental Regulation, Green Technology Innovation, and Industrial Structure Upgrading: The Road to the Green Transformation of Chinese Cities." *Energy Economics* 98 (2021): 105247.

24. Robinson, Sherry, and Hans Anton Stubberud. "Green Innovation in Germany: A Comparison by Business Size." *Journal of international business research* 12, no. 1 (2013): 47.

25. Pan, Xiongfeng, Shucen Guo, and Junhui Chu. "P2p Supply Chain Financing, R&D Investment and Companies' Innovation Efficiency." *Journal of Enterprise Information Management* (2021).

26. Tebaldi, Edinaldo, and Bruce Elmslie. "Does Institutional Quality Impact Innovation? Evidence from Cross-Country Patent Grant Data." *Applied Economics* 45, no. 7 (2013): 887-900.

27. Zhao, Lu, Honggui Gao, and Quan Xiao. "An Empirical Study on the Impact of Environmental Regulation on the Efficiency of Green Technology Innovation." *Statistics & Decision* 37, no. 03 (2021): 125-29.

28. He, Yaoyao, and Haiyan Li. "Probability Density Forecasting of Wind Power Using Quantile Regression Neural Network and Kernel Density Estimation." *Energy conversion and management* 164 (2018): 374-84.

29. Nasierowski, W, and FJ Arcelus. "About Efficiency of Innovations: What Can Be Learned from the Innovation Union Scoreboard Index." *Procedia-Social and Behavioral Sciences* 58 (2012): 792-801.

30. Chen, Kaihua, Mingting Kou, and Xiaolan Fu. "Evaluation of Multi-Period Regional R&D Efficiency: An Application of Dynamic Dea to China's Regional R&D Systems." *Omega* 74 (2018): 103-14.

31. Eilat, Harel, Boaz Golany, and Avraham Shtub. "Constructing and Evaluating Balanced Portfolios of R&D Projects with Interactions: A Dea Based Methodology." *European journal of operational research* 172, no. 3 (2006): 1018-39.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2021 doi:10.20944/preprints202111.0485.v1

32. Liu, Yaqin, Guohao Zhao, and Yushan Zhao. "An Analysis of Chinese Provincial Carbon Dioxide Emission Efficiencies Based on Energy Consumption Structure." *Energy Policy* 96 (2016): 524-33.

33. Sabir, Raja Irfan, and Raja Moazzam Sabir. "Managing Technological Innovation: China's Strategy and Challenges." *Journal of Technology management in China* (2010).

34. Chen, Yu, Mengke Zhu, Junlin Lu, Qian Zhou, and Wenbo Ma. "Evaluation of Ecological City and Analysis of Obstacle Factors under the Background of High-Quality Development: Taking Cities in the Yellow River Basin as Examples." *Ecological Indicators* 118 (2020): 106771.

35. Peng, Jiachao, Rongrong Xu, Lina Fu, Ming Yi, and Yaodong Xu. "The Evolution Pattern of Green Innovation Efficiency of Industrial Enterprises in the Yangtze River Economic Belt." *China Environmental Science* 39, no. 11 (2019): 4886-900.

36. Lin, Woon-Leong, Jun-Hwa Cheah, Mohamed Azali, Jo Ann Ho, and Nick Yip. "Does Firm Size Matter? Evidence on the Impact of the Green Innovation Strategy on Corporate Financial Performance in the Automotive Sector." *Journal of Cleaner Production* 229 (2019): 974-88.

37. Sui, Daniel Z. "Tobler's First Law of Geography: A Big Idea for a Small World?" *Annals of the Association of American Geographers* 94, no. 2 (2004): 269-77.

38. Lanoie, Paul, Michel Patry, and Richard Lajeunesse. "Environmental Regulation and Productivity: Testing the Porter Hypothesis." *Journal of Productivity Analysis* 30, no. 2 (2008): 121-28.

39. Wentao, Yu. "Research on Creative Industry Agglomeration and Its Production Efficiency -- an Empirical Analysis Based on Provincial Capital and Sub Provincial Cities." *Economist* 6, no. 6 (2016): 51-57.