Study on the Coupling Interaction of Green Technology Innovation, New Energy Industry Agglomeration and Carbon Emission Efficiency

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Abstract. This study examines the relationship between green technology innovation, new energy industry agglomeration and carbon emission efficiency from 2008 to 2019 in 30 provinces in China (apart from Tibet, Hong Kong, Macao, and Taiwan). According to the study, the mean value of the three couples’ average coupling coordination degree is between 0.03 and 0.49, which means that they are still in the maladjustment stage and on the verge of forced coordination. And the dynamic PVAR model is further established to study and conclude that green technology innovation is fostered by carbon emission efficiency, which is also boosted by new energy industry agglomeration. However, there is no correlation between green technology innovation and new energy industry agglomeration, and the three systems have not formed a good circular driving effect temporarily.

Keywords. Green technology, new energy industry, carbon emission efficiency, super-SBM model, coupling coordination degree, PVAR model

1. Introduction

Chinese economy has maintained a steady growth with high speed, yet accompanied with high pollution, energy consumption and discharge, which results in resource shortage and other environmental problems. The 18th National Congress of CPC has pointed out that China needs to revolutionize the energy production and consumption industry. One way is to reduce consumption and save energy, while another is to fervently encourage the growth of low-carbon enterprises. And the “Fourteenth Five-year plan” has proposed the modern industrial system to develop the strategic emerging industries. Among them, the new energy industry, in particular green technology, is crucial in reducing carbon emissions. It is not yet clear whether a good and effective interaction can be formed by promoting the improvement of carbon reduction efficiency under joint support of the green technology and new energy industry.

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2. Literature Review

Green technology innovation, new energy industry agglomeration and carbon emission efficiency have become hot topics for domestic and foreign scholars. Wang [1] analyzed the CO₂ emission rates of 23 countries and concluded that advances in technology have a favourable effect on carbon effectiveness. Liu [2] studied the effective promotion between carbon emission efficiency and technological innovation from the Chinese level. Technology is crucial to the growth of the new energy market [3]. Guo [4] used structural equation modelling to conclude that the level of technological innovation influences the formation of new energy industry clusters in a favorable way. Bai [5] explored that technology development could positively regulate the green power industry development. With the renewable power industry's exponential development, Xu [6] investigated how carbon emissions and new energy interact at the provincial level in China and concluded that there are geographical variations in how carbon emissions affect the new energy industry. Ren [7] studied that the new energy industry would initially increase carbon output and reduce carbon emissions at a later stage.

To sum up, there are many studies on the pairings of green technology innovation, new energy industrial agglomeration and carbon emission efficiency in existing studies, and few of them are studied in one system. Therefore, this paper studies whether the three factors promote each other, providing some help for the research on carbon emission reduction in China.

3. Research Methods and Data Sources

3.1. Research Methods

3.1.1. Entropy Value Method

To avoid errors caused by subjective factors in data processing, the data should be done. According to the research of Zhou [8], the entropy value method is selected.

Supposing there are \( r \) years, \( n \) provinces, and \( p \) indicators. And \( X_{ijt} \) is secondary index value of \( J \)th term of province \( I \) in \( t \) year. First, the standardized secondary index \( f_{ijt} \) was obtained. Then, the characteristic value \( h_{ijt} \) and information entropy redundancy \( d_j \) are calculated. Finally, The \( J \)th second-level index's weight \( w_j \) is determined. The conversion equations are as follows equations (1)-(5):

Positive indicator: 
\[
    f_{ijt} = \frac{x_{ijt} - \min(x_{jt})}{\max(x_{jt}) - \min(x_{jt})}
\]

Negative indicator: 
\[
    f_{ijt} = \frac{\max(x_{jt}) - x_{ijt}}{\max(x_{jt}) - \min(x_{jt})}
\]

\[
    h_{ijt} = \frac{x_{ijt}}{\sum_{t=1}^{r} \sum_{i=1}^{n} f_{ijt}}
\]

where \( x_{ijt} \) is the secondary index value of the \( J \)th term of the \( I \)th province in the \( t \)th year.
3.1.2. Super-SBM Model

The super-SBM model offers the advantages of more effective processing of unwanted outputs and further comparison of effective decision units when compared to the conventional DEA model. Based on the relevant studies of Wu [9] and Ning [10], here is the built-in super-SBM model:

\[
\begin{align*}
    d_j &= 1 + \frac{1}{\ln r_b} \sum_{t=1}^{n} \sum_{i=1}^{r} h_{i,t} \ln (h_{i,t}) \\
    w_j &= d_j / \sum_{j=1}^{n} d_j
\end{align*}
\]

(4)

(5)

3.1.3. Coupled Coordination Model

The degree of coordination of coupling primarily reflects the degree of coordination consistency among them. For accurately measure the coupling and coordination among the three systems of green technology innovation, new energy industry agglomeration and carbon emission efficiency, this paper builds the following model:

\[
\begin{align*}
    \min \ p &= \frac{1}{s} \sum_{j=1}^{s} \frac{Y_j}{X_{i0}} \\
    \text{s.t. } \bar{x} &\geq \sum_{j=1, j \neq 0}^{n} \lambda_j x_j, \bar{y} \leq \sum_{j=1, j \neq 0}^{n} \lambda_j y_j, \bar{x} \geq x_0, \bar{y} \leq y_0, \bar{y} \geq 0, \lambda_j \geq 0
\end{align*}
\]

(6)

(7)

(8)

(9)

Where, \( C \) stands for the coupling degree between green technology innovation, new energy industrial agglomeration and carbon emission efficiency. \( T \) stands for a degree in comprehensive development. \( D \) stands for the coupling coordination grade. \( \alpha, \beta, \) and \( \delta \) in the expression stand for the undetermined coefficients of green technological

\[
\begin{align*}
    &\min \ p \quad \text{represents the comprehensive technical efficiency value, } X_0 \text{ and } Y_0 \\
    \text{represent the input and output of the evaluation unit, respectively, and } \lambda \text{ is the weight vector. } \min \ p < 0.5 \text{ means the regional CO}_2 \text{ emission efficiency is invalid, } \min \ p \in [0, 5, 1] \text{ means the regional CO}_2 \text{ emission efficiency is weak efficiency, and } \min \ p \geq 1 \text{ means the regional CO}_2 \text{ emission efficiency is effective.}
\end{align*}
\]
innovation, the agglomeration of new energy industries, and carbon emission efficiency, respectively, while $\alpha = 0.4$, $\beta = 0.3$, $\delta = 0.3$ were selected by asking expert opinions and reading literature in this study.

3.1.4. PVAR Model

To further analyze the interaction among the three variables. This paper chooses to establish a panel vector auto-regression model. The constructed PVAR model is as follows:

$$Y_{it} = \alpha_0 + \sum_{j=1}^{\bar{Y}} \beta_{ij} Y_{t-j} + \gamma + \eta_t + \mu$$  \hspace{1cm} (10)

where, $Y_{it}$ represents the vector of the endogenous variable in the $i$th region in the $t$ year (including new energy industry agglomeration, green technology innovation and carbon emission efficiency), and $Y_{t-j}$, represents all endogenous variables, $\alpha_0$, $\beta_{ij}$, $\gamma$, $\eta_t$, and $\mu$ represent intercept, regression coefficient matrix, fixed effect, time effect and random error, respectively. The software used in this article is StataIC 15.

3.2. Variables Selection

3.2.1. Green Technology Innovation (GTE)

There is no a single metric used consistently by existing studies to quantify innovation in green technology. Referring to the methods of Fan [11] and Wu [12], this study searched the data of green patents in the Chinese Intellectual Property Office, took “pollution controls, pollution treatments, environmental chemical products, etc.” as the keywords and used the paired number to represent green technological innovation.

3.2.2. New Energy Industry Agglomeration (LQ)

Drawing on the methods purported by Wang [13] and Li [14], the development status of the new energy sector is reflected by the number of employees in the general equipment manufacturing industry and the electrical machinery and equipment manufacturing industry. The calculation formula is as follows:

$$LQ_i = \left( \frac{Y_i}{\sum_j Y_j} \right) / \left( \frac{\sum_i Y_i}{\sum_j \sum_i Y_i} \right)$$  \hspace{1cm} (11)

where, $LQ_i$ stands for the quotient of location of the sector $i$ in region $j$, $Y_i$ stands for the number of workers in sector $i$ in region $j$, $\sum_i Y_i$ stands for the total workers in region $j$, $\sum_j Y_j$ stands for the total workers in sector $i$ in China, and $\sum_i \sum_j Y_i$ stands for the total workers in China.

3.2.3. Carbon Emission Efficiency (CTE)

To calculate each Chinese province's carbon emission efficiency, the super-SBM model was established. Thereinto, capital investment refers to the provincial financial assets
calculated according to Zhang’s [15] research method, energy input refers to the total energy use of each province, and labor input refers to the number of urban employment. Expected output GDP is real GDP with 2000 as the base period. Undesirable output CO₂ emissions is calculated by referring to the "IPCC Guidelines" (2006) to calculate the total carbon emissions of eight major energy sources such as coal, gasoline, and fuel oil.

3.3. Data Sources

The research sample for this paper involves panel data from 30 provinces (municipalities and autonomous areas) in China from 2008 to 2019. (The relevant data of Tibet, Hong Kong, Macao and Taiwan regions are obviously missing, so they were considered to be removed.) The State Intellectual Property Office, China Industrial Statistical Yearbook, China Energy Statistical Yearbook, and other institutions provide the bulk of the data. And some missing data are supplemented by the interpolation method.

4. Empirical Results Analysis


Table 1 shows the coupling coordination degree among green technology innovation, new energy industry agglomeration, and carbon emission efficiency for 30 Chinese provinces from 2008 to 2019. It is obvious that coupling coordination degree of the system from 2008 to 2019 is distributed between 0.02 and 0.53. It includes the coordination grade of extremely dysfunctional recession, severe dysfunctional recession, moderate dysfunctional recession, mild dysfunctional recession, near dysfunctional recession and barely coordinated development.

From the perspective of time development, the national average of the coupling degree of green technology innovation, new energy industry agglomeration and carbon emission efficiency has been developing steadily from 2008 to 2019, and it is in a state of mild imbalance recession. In short, in the development process of nearly ten years, China's green technology innovation, new energy industry agglomeration and carbon emission efficiency are still in an unbalanced stage. There is still a certain gap to achieving the initial coordinated development. In the past ten years, two provinces have improved. Anhui has developed from mild disorder to near disorder, and Guizhou has developed from severe disorder to moderate disorder. In 2008, Jiangsu, Zhejiang and Guangdong provinces were in a positive coupling state, but their development has been backward, and now they are on the verge of disorder. Shandong, Liaoning, Inner Mongolia and Qinghai also have a trend of backward development. And it is necessary to strengthen measures to promote the coordination relationship among green technology innovation level, new energy industry agglomeration and carbon emission efficiency, to achieve a positive development trend. In other provinces and cities, the coupling coordination degree has been in a stable development state during the decade. It is clear that the three systems of carbon emission efficiency, new energy industry agglomeration, and green technology innovation level have not yet reached the stage of coordinated development and are currently at the stage of imbalance. However, with
the promulgation and implementation of various policies, the coupling coordination among the systems will gradually evolve into low-level coordination and high-level coordination.

### 4.2 Interactive Correlation Analysis of Green Technology Innovation, New Energy Industry Agglomeration and Carbon Emission Efficiency

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Note: Due to a large amount of data and typographical limitations, the relevant data for 2010 and 2014 are not presented.

4.2 Interactive Correlation Analysis of Green Technology Innovation, New Energy Industry Agglomeration and Carbon Emission Efficiency

To further examine the interaction among green technology innovation, new energy industry agglomeration and carbon emission efficiency, the dynamic relationship among them is analyzed by using the PVAR model.

4.2.1 Stationary Test

A unit root test must be run prior to model regression for preventing erroneous regression. At the same time, the IPS test, the LLC test and the Fisher-ADF test were adopted to guarantee the test's correctness. LnGTE and CTE variables were not stable after the test, and dCITE variables were still not stable after the first-order difference.
However, after the second-order difference, the 1% significance level test was successful for each of the variables. That is, the original non-stationary variables were obtained after the second-order difference to obtain stable data.

4.2.2. Co-integration Test

Westerlund and Pedroni tests are used in this research to determine whether there is a co-integration relationship among the three variables because the model contains second-order single integral variables. The two test methods' p values are both less than 1%, strongly rejecting the null hypothesis. Therefore, the three variables have a stable equilibrium connection over a long period.

4.2.3. PVAR Model Estimation

The optimal lag number of the model should be determined before GMM estimation. According to AIC, BIC, and HQIC criteria, the model's ideal lag order was discovered to be 1. The model is modified for the following test after the ideal lag order has been identified. The model estimation results obtained in this paper are shown in Table 2. It is observed that the first-order lagging new energy industrial agglomeration and the first-order lagging carbon emission efficiency both pass the 10% significance test, which indicates that they have a significant influence on carbon emission efficiency and green technology innovation, respectively. However, the first-order lag of the innovation in green technology and the agglomeration of the new energy industry failed to pass the 10% significance test, which indicate they have not promoted each other but only played a one-way promotion role. In addition, there is no interactive relationship between green technology innovation and new energy industry agglomeration, which are mainly affected by their own lag period. In general, green technology innovation, new energy industry agglomeration and carbon emission efficiency are still in a certain running-in stage, and the interaction among the three needs to be improved.

<table>
<thead>
<tr>
<th>Table 2. Estimation results of PVAR model.</th>
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<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Lh_ddCTE</td>
</tr>
<tr>
<td>(0.000)</td>
</tr>
<tr>
<td>Lh_ddLnGTE</td>
</tr>
<tr>
<td>(0.345)</td>
</tr>
<tr>
<td>Lh_ddLQ</td>
</tr>
<tr>
<td>(0.087)</td>
</tr>
</tbody>
</table>

Note: h_ represents the forward mean difference of the variable, L. represents the lag order 1, and the p-value of the correlation test is in parentheses.

4.2.4. Impulse Response Analysis

In order to study the degree of dynamic influence among the three, impulse response analysis is needed to explore. Pulse response results of each variable were obtained through 200 Monte-Carlo simulations, as shown in Figure 1. The dotted line represents the bound range at the 95% confidence level, the amount of lag periods where the shock occurred is displayed by the horizontal axis (unit: year), and the amount of the explained factor's reaction to the explanation factor's shock is displayed by the vertical axis (i.e. the impulse value).
The impulse response diagram of new energy industry agglomeration, green technology innovation and carbon emission efficiency is shown in Figure 1. They all have a convergence trend, which indicates that the model is stable. Green technology innovation, new energy industry agglomeration and carbon emission efficiency are all affected by one standard deviation of their own, and have a direct positive effect. As time goes on, theirs promoting effect gradually weakens until it converges to 0. This indicates that the three variables all have their own strengthening mechanisms and gradually weaken over time.

Affected by one standard deviation of innovation in green technology, the current carbon emission efficiency has no response and shows a negative impact. But after reaching the peak in the first cycle, it shows a positive impact. This shows that in the early stage, green technology is expected to reduce production costs, and a buffer period is needed before significant effects can be brought, and only then can carbon emission efficiency be effectively improved. Affected by one standard deviation of new energy industry agglomeration, carbon emission efficiency doesn’t respond in the current period, showing a positive effect, which is consistent with the model estimation result.

Green technology innovation is negatively impacted by one standard deviation of carbon emission efficiency, but subsequently shows a positive influence and then varies up and down. As a result, the level of green technical innovation will initially restrict carbon dioxide emissions efficiency, which demonstrates that carbon dioxide emissions efficiency will momentarily impede the development of green technology innovation. Both of them have a temporary mutual inhibition at the beginning, but with the passage of time, they form a good promotion effect. Affected by one standard deviation of new energy industry agglomeration, the green technology innovation theory did not respond in the current period. It then showed a positive effect, but the response degree was not large, and failed to play a good promotion role.

After being impacted by one standard deviation of carbon emission efficiency, new energy industry agglomeration had an obvious positive effect in the current period, and then the positive effect gradually weakened. It indicates the promotion of carbon emission efficiency had a good promotion effect on China’s new energy industry. After
being impacted by one standard deviation of green technology innovation, new energy industry agglomeration presents a first negative and then a positive impact. Given that the new energy industry agglomeration has not yet established a positive trend, it is possible that green technology innovation has a restraint effect on it. As time goes by, the agglomeration advantage of new energy industry becomes prominent. Green technology innovation can play a role and promote it.

5. Conclusions and Recommendations

This study examines the dynamic association between green technology innovation, new energy industry agglomeration and carbon emission efficiency using panel data from 30 Chinese provinces from 2008 to 2019 (excluding Tibet, Hong Kong, Macao, and Taiwan). The following conclusions are drawn:

First, the mean coupling coordination degree of green technology innovation, new energy industry agglomeration and carbon emission efficiency is between 0.03 and 0.49, which is still in the maladjustment stage and close to the barely coordinated stage. However, there is still a gap between quality and coordinated development, and there is still a lot of room for growth.

Second, from the dynamic association analysis of three variables, green technological innovation, new energy industrial agglomeration and carbon emission efficiency haven’t formed a good interaction. Green technology innovation is influenced by carbon emission efficiency, and the growth of the new energy industry also influences carbon emission efficiency. However, there is no correlation between the growth of green technologies and the concentration of the new energy sector. They are still in a certain running-in stage, and their interaction still needs to be improved.

The following recommendations are offered in light of the previous results:

First, continuing to promote green technological innovation. China’s energy saving and reducing emissions efforts still have a lot of potential for improvement and optimization. All provinces can focus on supporting the innovation of green technology in terms of policies, increase cooperation between universities and enterprises in various regions, and actively encourage the transition of green technology and its application in the new energy sector. Vigorously carry out innovation of green technology, argument the output of green products, and innovation in green technology should take the lead.

Second, optimizing the significance of the new energy industrial agglomeration. Industrial agglomeration will bring a certain spillover effect, but through dynamic research, it is found that the new energy industrial agglomeration effect is not well reflected. Therefore, all provinces should optimize the spillover effect of new energy industry agglomeration and strengthen cooperation among provinces. Provinces with a relatively high concentration of new energy sector agglomeration should boost the adoption of green technology, increase their radiation capacities, and create local new energy industry clusters. For provinces with relatively low new energy industry agglomeration, the government should strengthen the guidance of relevant policies, introduce new energy industry through preferential policies, communicate more with provinces with high concentration of industry, learn excellent technology and development mode, and realize leap-forward development.

Third, formulating the direction of development in light of local conditions to achieve coordinated development among regions. The study found that the overall...
development of the eastern areas is better than the development of the central areas and western areas, and the regional development differentiation is more obvious, regardless of the degree of innovation in green technology, the concentration of new energy industries, or the value of carbon emission efficiency. Therefore, the eastern region should continue to actively learn from advanced experience and further expand green technologies and new energy industries to boost carbon emission reduction, while also playing a leading role in the advancement of the central and western areas. Utilizing the plentiful local resources will help the central and western areas establish the new energy industry more quickly, increase full investment in scientific research, and continuously upgrade the level of green technology innovation.

References