Does Eco-innovation Improve Green Total Factor Productivity of China's Industry?

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Abstract: The improvement of industrial green TFP is crucial for the sustainability of economy and environment. And the eco-innovation directly improves the industrial green TFP. However, there are few studies on the relation between eco-innovation and industrial green TFP. Based on the relevant data from 2006-2015 of 30 provinces in China, using SBM model this study firstly evaluates the industrial green TFP of each province by measuring the desirable output and undesirable output. Then the eco-innovation is measured by patent application quantity and further divided into breakthrough and incremental innovation by patent quality. The results show that eco-innovation improves the development of green industry in China. The promotion from breakthrough innovation is prominent. However, the incremental innovation restrains the development of green industry in China.

1 Introduction

With the increasing development of industrialization of China, the extensive economic development pattern has caused many problems on environment and resources. People started to realize the importance of the economic growth and environmental sustainability. Industry is one of the pillars for China's economy, and it is also the primary source of pollution and resource shortage [1]. Therefore, the green development of industry is necessary for the economic transformation in China. The green development of industry improves the resource utilization and reduces the impact on environment depending on the technical and organizational ability of resources allocation. That is, using less input of resources to achieve more economic and environmental performance. As far as the technical ability is concerned, the low-carbon technology is regarded as an important means of balancing the economic and environmental goals [2]. However there are few studies connecting green development of industry and low-carbon technology. In recent research, the eco-innovation is divided into breakthrough innovation and incremental innovation according to their contributions, and the former has a bigger significance for the transformation of production system and the green development [3-4].

This study provides an empirical analysis on the relation between eco-innovation and green development of industry based on the relevant data from 2006-2015 of 30 provinces in China, and differentiates the impact of breakthrough innovation and incremental innovation on green development of industry. And this study has the following contributions: Firstly, the study uses Malmquist-Luenberger index model based on SBM

directional distance function to measure the green TFP of 30 provinces in China by calculating the energy input, desirable and undesirable output, which is more objective and comprehensive. Secondly, different from general technological activities, the study selects the eco-innovation which can meet the requirement of green development better to analyze its impact on the green TFP of China's industry. The patent applications are adopted to measure the level of eco-innovation. Thirdly, the resource organization factors, such as human capitals, marketization degree, industrial structure, economic openness, and environmental regulation are also covered in this study as the drivers to improve the green development of industry, which are usually ignored in many research.

2 Measurement of industrial green TFP

Referring to the research of Jahanshahloo et al. [5] and APARICIO J et al. [6], this study uses DEA and regards each province of China as a decision-making unit (DMU) to establish a Slack-Based Model (SBM) proposed by Tone [7] when considering the evaluation of DMU with undesirable output. When $p^*=1$, the DMU is strongly efficient, and there is no weak-form efficiency of radial model. When $0 \leq p^* \leq 1$, the DMU has an efficiency loss, and the input-output can be improved by increasing the proportion of the slack variables to each variable in the input-output.

The study uses the relevant data of 30 provinces in China from 2006-2015. The data of input factor, desirable output and undesirable output come from the China Industry Statistical Yearbook, China Labour Statistical Yearbook, and China Energy Statistical

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Yearbook. The data of various price indices come from China Statistical Yearbook.

In order to clearly present the internal commonalities and characteristics of green TFP among different areas, China is divided into East, Central and West (see Table 1). The industrial green TFP in eastern China is relatively higher, above the national average. The reasons are that the economy in eastern China mainly relies on the development of high and new technology industry with lower energy consumption. The education level is higher, and people in eastern China have stronger awareness of environmental protection. The industrial green TFP in

central China is relatively lower, because central China covers main heavy industrial areas. The industry in this area relies on high consumption of energy, and the environment is sacrificed for economic development. The pollution in western China is lower than that in central China due to smaller population and lower degree of industrialization there. The industrial green growth rate of the whole China shows an increasing tendency over years, indicating that China began to pay attention to the protection of ecological environment when pursuing economic development. The specific results are shown in Table 1.

Table 1 Industrial Green TFP by Areas

Year	China	Eastern China	Central China	Western China
2006	0.7269	0.8229	0.5968	0.7557
2009	0.6781	0.8367	0.5843	0.5653
2012	0.8595	0.8686	0.8077	0.9167
2015	0.8659	0.9522	0.7626	0.8914

3 Empirical Applications

3.1 Model Specification

According to prior research, this study considers the impacts of industrial structure, degree of marketization, exports, emission reduction goals, and human capital on industrial green TFP of China. The model is specified as Eqs. 1.

$$\ln IGTFP_{it} = \alpha_0 + \alpha_1 Y02_{it} + \delta \ln X + \varepsilon_{it} \quad (1)$$

IGTFP represents the industrial green TFP, and it is a dependent variable; Y02 represents the eco-innovation, and it is a core variable, respectively representing total low-carbon technology, breakthrough technology and incremental technology in different models; X represents the control variables that may impact the industrial green TFP, including industrial structure (IS), degree of marketization (MD), export (EX), emission reduction goals (EG), and human capital (HC); ε_{it} presents the residuals.

3.2 Dataset and variables

In recent years, research uses the Y02 classification of low carbon patent applications in the CPC (Cooperative Patent Classification) issued by the United States and the United Kingdom in 2013 to measure the innovation activities. For measuring the patents applications of China, this study only covers the patents applications from Chinese citizen, and excludes the foreign applications in China [8-9]. This study uses Y02 patents to measure eco-innovation, and the data come from

incoPat Global Patent Database. Based on prior research, this study uses the top 1% citation impact in defining the breakthrough low-carbon technology, and uses the patents with the top 5% citation impact for robustness test.

Considering that industrial green TFP is also influenced by industrial structure, human capital, export and other variables, based on prior research [10-11] this study selects industrial structure (IS), degree of marketization (MD), export (EX), emission reduction goals (EG) and human capital (HC) as control variables.

3.3 Results

In order to verify the factors influencing the industrial green TFP of China, this study uses the panel data of 30 provinces from 2006 to 2015 to establish a regression model. The results are shown in Table 2.

Firstly, only considers the effect of control variables on China's industrial green TFP to examine the reasonability of selected influencing factors (see Model 1 in Table 2). Secondly, the total low-carbon technology variable is introduced in the model to examine its effect on industrial green TFP (see Model 2 in Table 2). And then, dividing the total low-carbon technology into breakthrough and incremental technology according to the patent quality to examine the effects of various types on China's industrial green TFP (see Model 3 in Table 2). Finally, due to the limited research scope, changes the core independent variables on the basis of the original model in order to remove the contingency of result. This study adopts the patents which are in top 5% of citation frequency to replace that are in top 1% for robustness test (see Model 4 in Table 2). The panel data

model contains the fixed effect and random effect model, so the Hausman test is required to determine the corresponding model for regression. The Hausman test results of the two models show that the random effect model should be selected in this study. The further

analysis on the economic implications of results also indicates that the random effect model is more reasonable. The implications from the model results are as follows:

Table 2 Model Analysis Results

variables	Model 1	Model 2	Model 3	Model 4
Y02	-	0.00015** (0.000053)	-	-
lnBre	-	-	0.00282* (0.00148)	0.00105*** (0.000282)
lnIncr	-	-	-0.000415** (0.0000176)	-0.000765*** (0.0000194)
IS	-0.719*** (0.16)	-0.668*** (0.165)	-0.697*** (0.16)	-0.769*** (0.158)
MD	0.338*** (0.066)	0.299*** (0.073)	0.330*** (0.066)	0.353*** (0.0646)
EX	-20.95*** (3.216)	-20.98*** (3.213)	-19.14*** (3.695)	-0.635* (0.362)
EG	-0.732** (0.367)	-0.767** (0.368)	-0.861** (0.369)	-19.84*** (3.631)
HC	0.473** (0.215)	0.477** (0.215)	0.411* (0.237)	0.275 (0.232)
Constant	1.057*** (0.097)	1.051*** (0.0967)	1.080*** (0.0976)	1.064*** (-0.0946)
Observations	300	300	300	300
R-squared	0.243	0.247	0.257	0.283

Note. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01.

3.3.1 The impact of core independent variables on industrial green TFP

Total low-carbon technology (Y02). The total low-carbon technology improves the industrial green TFP of China with a coefficient of 0.00015 at the 5% significance level, which is consistent with the expectation. The result indicates that the eco-innovation is conducive to the industry greenization and sustainable development in China.

Breakthrough technology (lnBre) and incremental technology (lnIncr). The breakthrough low-carbon technology has a positive effect on China's industrial green TFP and passes the significance test. It indicates that the breakthrough low-carbon technology is conducive to improve China's industrial green TFP. It can provide strong technological supports for the accelerated development of green economy in China. But the effect of breakthrough low-carbon technology is weak. The possible reason is that the commercialization of patents still faces significant obstacles [12]. However, the incremental low-carbon technology has a significantly negative effect on China's industrial green TFP and restrains the green transition of China's

economy. It indicates that the pollution emissions due to scale production resulting from incremental technological innovation exceed the emission reduction effect of the technology itself. That is, the scale effect exceeds the emission deduction effect.

3.3.2 The impact of control variables on industrial green TFP

Industrial structure (IS) has a significant restraint on China's industrial green TFP, showing that the higher the proportion of value-added of secondary industry in GDP, the greater the pressure on the environment, and the more it hinders a green transition of economy. The degree of marketization (MD) has a high promotion on China's industrial green TFP at the 1% significance level. It shows that the current market incentive mechanism is conducive to save the resources and energy, and it is an important driver to promote the green development. Export (EX) has a restraint on China's industrial green TFP. The possible reason is that China's export structure is still dominated by low-quality manufacturing industry, and still at the middle and low end of the global value chain. The pull of external demand not only promotes the economy, but also increases the energy consumption, and

brings great pressure on the environment in the short term. Emission reduction goals (EG), as the main policy tool for the government to prevent and control environmental problems, should improve the industrial green TFP, but the model shows the reverse result. The possible reason is that the implementation of policy has a certain hysteresis, so the effect is not obvious in the short term. Human capital (HC), as a key factor to promote economic transition, shows a very significant promotion on China's industrial green TFP at the 1% significance level.

The results of Model 4 in Table 2 show that the effects of breakthrough technology and incremental technology on China's industrial green TFP are positive and negative respectively. Although the effect coefficients of the two types of technology on industrial green TFP are different, the effect directions are consistent with the results shown in Model 3, which indicates that the research results are robust.

4 Conclusions

This study adopts the SBM model to calculate China's industrial green TFP from 2006 to 2015 by considering both the desirable output and undesirable output. Furthermore, divides the low-carbon technology into breakthrough technology and incremental technology according to the patent quality, and measures the effects of the two types of technology on China's industrial green TFP. The results are as follows: (1) the industrial green TFP of whole China is not high, and the spatial distribution shows that it is higher in eastern China and lower in western China. The industry greenization level in developed areas along the east coast is higher, while the green efficiency value in central and western China is relatively lower. (2) Eco-innovation as a whole is conducive for the green development of China's industry. (3) Breakthrough low-carbon technology can better promote the green TFP of China's industry. By contrast, the incremental low-carbon technology restrains the green TFP of China's industry. Its scale effect exceeds emission reduction effect. (4) The degree of marketization and the promotion of human capital constitute the important driving force of China's industrial green development; however, affected by the development stage of China and time lag effect, the industrial structure, export and emission reduction goals currently constraint the growth of China's industrial green growth rate.

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