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Estimation of innovation's green performance: A range-adjusted measure approach to assess the unified efficiency of China's manufacturing industry

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ABSTRACT

A DEA-RAM model is adopted to study the unified efficiency of innovation's green performance in 29 sectors of China's manufacturing industry over the period of 2005–2012 in this paper. This study provides evidences that innovation in China's manufacturing industry shows a shift to green innovation and contributes increasingly to green growth. However, the lag in the environmental efficiency remains a major constrain for improving innovation's green performance of China. A significant regional disparity exists in the unified efficiency between western and eastern areas of China. The gap in the unified efficiency tends to increase across regions.

1. Introduction

As the environmental problems become more and more serious, scholars' research perspectives on innovation management and innovative economy have gradually changed that they turn to pay more attention to considering the value of technological innovation from an ecological perspective instead of analyzing the significance of technological innovation from the perspective of economic value (Jaffe and Stavins, 1995; King and Lenox, 2001; Noci and Verganti, 1999). Currently, research on green innovation that analyze the influencing factors of green innovation and find out the key factors that promote green innovative transformation increasingly attract scholars' attention (Baker and Shittu, 2006; Bergh et al., 2011; Chen, 2008; Fraj-Andrés et al., 2008 . Horbach, 2008; Valentine, 2010 . Woo et al., 2014). The influence of enterprise scale, enterprise collaboration, economic benefits and environmental regulations on enterprises' green innovation have been studied by these scholars. And the performance of green technological innovation has been analyzed by few scholars such as Han (2012), Zhang and Zhu (2012) and Feng (2013) based on innovation efficiency model which consists of R&D investment, energy input, innovation output and environmental output. Besides, the whole industry and the industry in different regions in China have been studied mainly on the green output efficiency of R&D sector. The results show the green efficiency of Chinese industry's R&D sector is generally low. However, the analysis of unified efficiency of innovation policy within a DEA model has not been seen in the literature. Relying on a panel data of various manufacturing subsectors in China, our study aims to fill this gap. In this paper, green technological innovation performance of manufacturing industry in China is studied especially on the manufacturing sub-sectors which Han Jing, Zhang Jiang Xue, Feng Zhijun and other scholars have not referred to.

As rapid industrialization in China has raised concerns about resources constrains and environmental pollution, the country is paying increasing attention to a green growth strategy. Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies (OECD, 2011).[1] Explicitly, transition to green growth calls for strengthening

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[1] See "The National Medium- and Long-Term Plan for the Development of Science and Technology" published in 2006, retrievable from http://english.gov.cn/2006-02/09/content_183426.htm.

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green innovation by improving resource use efficiency and reducing environmental impacts (Blok et al., 2015; Lozano et al., 2015). Innovating China's manufacturing industry, primary contributor to its economic growth, is a key in addressing economic and environmental challenges. Earlier analysis tends to suggest that Chinese firms remained stuck in commodity manufacturing, undifferentiated activities for which innovation is absent (Steinfeld, 2004). However, recent studies show that innovative manufacturing is a critical part of China's economic growth story (Nahm and Steinfeld, 2012). Indeed, since 2006, moving up the manufacturing value chain has been becoming a national goal - increase investments in research and development to 2.5 percent of GDP and reduce reliance on foreign technology by 30 percent by 2020.[1] Thereby, the question remains to be answered: to which extent does China's innovation underpin green growth of its economy?

In order to measure the unified efficiency of innovation in creating new products, services and process and also in improving environmental performance, a RAM (Range-Adjusted Measure) model in the DEA (Data Envelopment Analysis) literature is adopted. Following Sueyoshi and Goto (2011), our modeling approach allows for measuring the efficiency both on desirable outputs and on undesirable outputs in an integrated framework. This combined efficiency is referred to as "unified efficiency" in this study. Input separation – fossil-fuels consumption and research and development (R&D) – together with output separation – value of new products and pollutant emissions are considered. Based on the panel data consisting of 29 subsectors of China's manufacturing industry over the period of 2005–2012, the unified efficiency of R&D inputs on innovative and environmental performance are assessed. Thereby, our empirical analysis allows for investigating whether innovation enables green and growth to go hand-in-hand. Our findings may provide valuable insights into the role of innovation in green growth strategies for policy makers.

The remainder of the paper is organized as follows: Section 2 details the model. Section 3 presents data. Section 4 discusses the empirical results. Section 5 concludes with policy implications.

2. Methodology and models specification

According to literature review, it is found that there are non-parametric and parametric methods to measure efficiency. Classical or stochastic cost's estimation and production functions' estimation are involved in parametric methods. The estimation results vary substantially due to the different functional forms chosen. Besides, parametric methods do not incorporate undesirable outputs (Gillen and Lall, 1997). Index of total factor productivity and data envelopment analysis (DEA) are two main non-parametric methods. Information on factor prices and data on physical inputs and outputs are required in the former method. Whilst, DEA is a popular linear programming based technique that allows for constructing efficiency indices on the basis of multiple outputs and inputs without any information of prices and costs. The efficient decision making units (DMU) relate inputs with outputs subject to best practice technology, which is an advanced tool.

In existing studies, DEA has been extensively used to evaluate operational efficiency and environmental efficiency separately. Operational efficiency indicates how efficiently the desirable outputs of the production process are generated from the inputs used, while environmental efficiency is concerned with the relationship between desirable and the undesirable outputs of the production process (Korhonen and Luptacik, 2004). By far, there is limited studies on to assessing unified operational and environmental efficiency with the application of RAM. By adopting RAM, unified efficiency of Japanese fossil fuel power generation are assessed by Sueyoshi and Goto (2011). Besides, the unified efficiency of China's GDP output and carbon emissions are analyzed by Li (2013). The focus of this paper is assessing the innovation's green performance of manufacturing industry in China.

It assumes that there are nth DMUs that use a column vector of innovation inputs $k = (k_1, k_2, ..., k_W) \in R_W^+$ to yield a column vector of innovation outputs$p = (p_1, p_2, ..., p_I) \in R_I^+$ and use a column vector of energy inputs $e = (e_1, e_2, ..., e_m) \in R_m^+$ to yield a column vector of non-desirable outputs$h = (h_1, h_2, ..., h)v \in R_v^+$.

2.1. Operational efficiency of innovation

When measuring the operational efficiency, R&D capital and human capital inputs of innovation are investigated. For comparison purpose, this indicator for reflecting the pure efficiency without energy input factors in innovation process is specifically constructed. Therefore, the operational efficiency does not incorporate the energy inputs and the bad outputs and thus ignores the environmental aspect. Thus, the RAM model for operational efficiency of innovation is formulated as follows:

$$\begin{aligned} \max \quad & \sum_{w=1}^{W} R_w^k s_w^k + \sum_{i=1}^{I} R_i^p s_i^p \\ s.t. \quad & \sum_{j=1}^{J} k_{wj}\lambda_j + s_w^k = k_{wj}, \forall w \\ & \sum_{j=1}^{J} p_{ij}\lambda_j - s_i^p = p_{ij}, \forall i \\ & \sum_{j=1}^{J} \lambda_j = 1, \lambda_j \geq 0, \forall j \\ & s_w^k \geq 0, \forall w; s_i^p \geq 0, \forall i \end{aligned} \tag{1}$$

In model (1), s_w^k and s_i^p are slack variables related to inputs and desirable outputs of innovation, respectively. λ_j is a column vector of unknown variables (often referred to as structural or intensity variables) used for connecting the input and output vectors by a convex combination. R_w^k and R_i^p are the adjustment ranges for the inputs and outputs of innovation, determined by the upper bounds ($\max(k_{wj})$,$\max(p_{ij})$) and lower bounds (($\min(k_{wj})$,$\min(p_{ij})$) in Eq. (2).

$$R_w^k = \frac{1}{(w+i)\left[\max(k_{wj}) - \min(k_{wj})\right]}, R_i^p = \frac{1}{(w+i)\left[\max\left(p_{ij}\right) - \min\left(p_{ij}\right)\right]} \tag{2}$$

Model (1) allows measuring the level of inefficiency through the slacks as follows:

$$0 \leq s_w^{k^*} = k_{wj} - \sum_{j=1}^{J} k_{wj}\lambda^* \leq R_w^k, 0 \leq s_i^{p^*} = \sum_{j=1}^{J} p_{ij}\lambda^* - p_{ij} \leq R_i^p \tag{3}$$

where "*" refers to the state of an optimal value. The results in Eq. (3) follow the definition of the range and the condition$\sum_{j=1}^{J}\lambda_j = 1$. A solution of $s_w^{k^*}$ and$s_i^{p^*}$ can be obtained, representing the level of inefficiency at the state of optimal value (Sueyoshi and Goto, 2011).