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Total-factor ecology efficiency of regions in China

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ABSTRACT

This paper combines the concept of Ecological Footprint (EF) with the framework of total-factor energy efficiency to develop a new index of total-factor ecology efficiency (**TFEcE**), which is constructed as the ratio of the target EF input obtained from SBM (slack-based measure) model to the actual ecology input under the consideration of labor and capital inputs. This paper computes the **TFEcE** of 28 provinces in China for the period 2000–2012. Findings show that China's **TFEcE** remains a low level of 0.5, which urgently needs to be improved. China's regional **TFEcE** is extremely unbalanced and the eastern area ranks first with the highest score. Compared with total-factor energy efficiency and traditional single-factor ecological efficiency, The **TFEcE** index evaluates ecology efficiency more comprehensively through taking EF in conjunction with the total-factor framework.

1. Introduction

China's economy has grown aggressively in the past thirty-five years, as its GDP (gross domestic product) has grown by almost 150 times from 1979 to 2014 (National Bureau of Statistics of China, 2015). At the same time, severe ecological problems behind this prosperous scenario are becoming worse: China became the world's largest contributor of carbon dioxide emissions in 2007 and the largest energy consumer in 2010, China is also facing intensified soil erosion, increasing water pollution, stern grassland degradation, and haze pollution covering most of the land area. China's total ecological impact will not fall due to continued stable economic growth in the future. Along with this fast demand for ecology input, the efficiency of ecology should be of concern especially under China's pursuing overall improvement of the ecological environment in the 13th Five-Year Plan (2016–2020).

Ecological efficiency means doing more with less, or producing economic outputs with minimal natural resources and environmental degradation (Kuosmanen, 2005). Since first described by Schaltegger and Sturm (1989) and widely publicized in *Changing Course* (1992), ecological efficiency has been proposed as an effective means to transform unsustainable development to sustainable development (Mickwitz et al., 2006). Although ecological efficiency assessment is a complicated and multidisciplinary task (Zhao et al., 2006), it is widely measured as the ratio between the added value of a product or service and the ecological impacts of the product or service (Yu et al., 2013). In the empirical study, GDP is often used as the numerator, and consumption of energy (Hu and Wang, 2006), emissions of CO_2 (Zhang et al., 2008), domestic extraction used (Yu et al., 2013) or material flow (Wang et al., 2016) is usually placed in the denominator as indicators of ecological pressure. In the above literature, the ecological efficiency is measured in the presence of only specific resource input, neglecting other ecological impacts from humanity.

The most comprehensive measure of humanity's overall impact may be the Ecological Footprint (EF), which is firstly put forward by Rees (1992) and improved by Wackernagel and Rees (1996). Chen et al. (2004) stated that the ratio of GDP to EF can be considered as a measure of the resource efficiency. Fu et al. (2015) develops a new method of calculating the resource efficiency by using the EF as an indicator of the ecological input and GDP as the output.

The above studies either use a specific ecology input such as energy, water, or land, or use a comprehensive ecological input such as EF to construct the index of ecological efficiency. All these indices only take ecology into account as input to produce outputs. However, the fact is that ecology alone cannot produce any output. Ecology must be put together with other inputs such as labor, capital stock to produce GDP. Just like the single-factor energy efficiency index has been obtained widespread criticism (Patterson, 1996), single-factor ecological efficiency index in the previous literature would also lead to misleading conclusions. Therefore, a multi-input model considering other inputs in a total-factor framework should be applied to correctly assess the ecological efficiency.

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In a total-factor framework, Hu and Wang (2006) innovatively built the total-factor energy efficiency (TFEE) index using data envelopment analysis (DEA). Incorporating water as an input as well as using conventional inputs such as labor employment and capital stock, Hu et al. (2006) established an index of water efficiency based on the TFEE. Honma and Hu (2008) computed the regional TFEE in Japan for the period of 1993–2003 and discovered a U-shape relation between energy efficiency and per capita income for the regions in Japan. Zhang and Choi (2013), Zhao et al. (2014) analyzed the changes of TFEE in China at the provincial level considering capital, labor and energy as inputs and value added as output. Li and Hu (2012) initially computed the ecological total-factor energy efficiency (ETFEE) of 30 provinces in China taking into account undesirable outputs. Zhang et al. (2015) proposed a metafrontier slack-based efficiency measure approach to model ETFEE and empirically analyzed regional ETFEE of China during 2001–2010.

Although TFEE and ETFEE measure energy efficiency in a total-factor framework, both of them only take energy into account as the single ecological input while neglecting other ecological inputs such as cultivated input, forest input, grassland input, productive-water input, and build-up land input. Until now, as far as we know there has been no systematic research on the efficiency of a much wider spectrum of ecological inputs in the total-factor framework.

Following the idea of Hu and Wang (2006) proposing the total-factor energy efficiency, we use EF as the comprehensive proxy of ecology inputs to build a new index of ecology efficiency and have named it the total-factor ecology efficiency (**TFEcE**),[1] which is constructed as the ratio of the target EF input obtained from slack-based measure (SBM) model in a total-factor framework to the actual ecology input. Compared with the traditional single-factor ecological efficiency (i.e., ecological input/GDP), which only takes ecological input into account as a single input, "Total-factor" in TFEcE index of this paper means not only ecological input, but also capital and labor are taken into consideration as the key input factors to produce GDP.

The potential contributions of this paper are as follows. Firstly, different from the paper of Hu and Wang (2006), this paper extends the index of TFEE and replaces the energy in TFEE as EF, which is a more comprehensive index. Also, different from the existing papers relevant to the EF always using EF to evaluate single-factor ecology efficiency while neglecting other key input factors, this paper introduces EF into the total-factor framework, which expands the role of EF and combines it with economic analysis. To sum up, we combine the framework of the total-factor efficiency with EF to develop the new index of **TFEcE**. Secondly, we calculate the **TFEcE** of China's 28 provinces from 2000 to 2012 and clarify the discrepancy of **TFEcE** among eastern, middle, and western areas of China, Thirdly, we discuss the difference between **TFEcE** and traditional single-factor ecological efficiency neglecting labor and capital inputs, and we also analyze the difference between **TFEcE** and TFEE proposed by Hu and Wang (2006).

This paper is organized as follows. Section 2 presents our methodology of EF and **TFEcE**. Section 3 describes the data we used and evaluates the EF of 28 provinces in mainland China from 2000 to 2012. Section 4 provides the empirical study for the ecology efficiency of provinces in China based on **TFEcE**. Finally, Section 5 concludes this paper.

[1] The definition of "total-factor" is consistent with Hu and Wang (2006), who firstly proposed the concept of total-factor energy efficiency. Total-factor energy efficiency in their paper considers not only the energy input, but also capital stock and labor employment inputs.

2. Methodology

In this section, we first calculate EF as the comprehensive measurement of ecological resources occupied by humanity, then consider the EF as ecological input and introduce it into the SBM model, to calculate the **TFEcE** in a total-factor framework.

2.1. Ecological Footprint

EF is a simple evaluation method for sustainable development from the perspective of the total areas of productive land and water required to produce all the resources consumed and to assimilate all the wastes produced (WWF, 2006). The EF methodology converts the regional resource and energy consumption into a variety of biologically productive areas.

In this paper, the calculation of EF from 2000 to 2012 for China's 28 provinces is mainly based on the compound approach put forward by Wackernagel (Wackernagel and Rees, 1996; Wackernagel et al., 1999). EF is the sum of its six types ecologically production land, i.e., arable land, forest land, pasture land, water land, fossil energy land, build-up land. The computational formula for EF is as follows:

$$\mathrm{EF} = \sum \frac{P_i}{Y_{Pi}} * YF_i * EQF_i \tag{1}$$

In the formula above, EF is the total ecological footprint; i is the type of area of the biological productive land required; P_i is the consumption of ith type of resources by a certain human population; Y_{Pi} is the average productivity of producing ith type of resources in a certain productive area; YF_i is the yield factor of ith land type; EQF_i is the equivalence factor of ith land type.

2.2. SBM model

Built upon the basic CCR-DEA (Charnes et al., 1978) model, Tone (2001) proposed the SBM to measure efficiency based on input excesses and output shortfalls. Being a non-radial approach, SBM overcomes the conventional radial DEA method's overestimating-limitation which is caused by neglecting slack variables (Fukuyama and Weber, 2009). Furthermore, SBM directly accounts for input and output slacks in efficiency measurements, with the advantage of capturing the whole aspect of inefficiency (Zhang et al., 2015).

Assume that there are $n = 1, \ldots\ldots, N$ provinces in China, and each province uses input vector $\boldsymbol{x} \in \mathrm{R}_+^m$ to jointly produce output vector $\boldsymbol{y} \in \mathrm{R}_+^s$. In this paper, the output vector contains provincial GDP. The input vector contains capital stock, labor, and EF. The fractional programming problem of the constant-returns to scale SBM model is expressed as follows:

$$\text{Minimize} \quad \rho = \frac{1 - \left(1/m\right) \sum_{i=1}^{m} s_i^- / x_{io}}{1 + \left(1/s\right) \sum_{r=1}^{s} s_r^+ / y_{ro}}$$

$$\text{Subjected to} \quad \begin{aligned} & x_o = X\lambda + s^-, \\ & y_o = Y\lambda - s^+, \\ & \lambda \geq 0, s^- \geq 0, s^+ \geq 0. \end{aligned} \tag{2}$$

Where s_i^-, s_r^+, x_o and y_o represent the input slack, output slack, input and output for the oth province, respectively; S^-, S^+, X and Y are the corresponding matrices of the input slack, output slack, input and output; λ is a nonnegative multiplier vector. ρ is the overall efficiency score for the oth province. If $\rho = 1$ (which indicates that all the slack variables are 0), the oth province is SBM-efficient. If the slack of EF is 0, the oth province is ecological efficient.