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Estimating the regional total factor efficiency and pollutants' marginal abatement costs in China: A parametric approach

Kai Tang [a], Lin Yang [b,*], Jianwu Zhang [a]

[a] School of Economics and Trade, Guangdong University of Foreign Studies, 510006 Guangzhou, China
[b] School of Management and Economics, Beijing Institute of Technology, 100081 Beijing, China

HIGHLIGHTS

- China's regional total factor efficiency and pollutants' shadow prices are assessed.
- A parameterized non-radial directional distance function is used.
- There is a large scope for further energy saving and pollution abatement in China.
- The regional total factor efficiency and pollutants' shadow prices are heterogeneous.

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ABSTRACT

Applying a parameterized directional distance function approach, this paper estimates the regional total factor efficiency and pollutants' marginal abatement costs (MACs) in China covering the years 2003–2012. We find that if all provinces produced on the production frontier, China could potentially conserve energy consumption by 29.5%, and reduce emissions of carbon dioxide (CO_2) and sulfur dioxide (SO_2) by 28.2% and 27.4%, respectively. The provinces in southeast coastal area performed better than the rest of the country. The bulk of potentials for energy saving and pollution reduction appeared in middle Yellow River, northwest, north coast, and northeast areas. The MAC of CO_2 increased steadily and continuously, while that of SO_2 showed a sharp increase throughout the whole study period. The average MACs of CO_2 and SO_2 for the whole country were 5512 Yuan/tonne and 154,395 Yuan/tonne, respectively. The MACs of SO_2 in different areas were remarkably unbalanced. Our estimates suggest that the opportunities for double dividend of economic production and pollution reduction are potentially achievable. Policymakers are required to facilitate technology transfer and encourage scientific and technological cooperation between inter- and intra-area. Additionally, they should also consider the regional heterogeneity when making the reduction allocations within the economic sectors and make the market prices of pollutants flexible.

1. Introduction

It is widely acknowledged that economic activities are directly or indirectly associated with energy consumption, which further results in corresponding pollution such as SO_2 and CO_2 emissions [1]. The potential exhaustion of non-renewable energy and the growing concern over environmental pollution have required more efficient use of energy and reduction of energy-related pollutants emissions. For many developing countries like China, the undoubted importance of achieving sustainable development have led to the present goals of energy saving and pollution reducing to be expressly incorporated into the national schemes that accelerate the local economic growth. In doing so they hope minimize the resource and environment costs of economic activities.

China has experienced rapid economic growth over the past decades, yet, it is also facing serious issues regarding excessive energy consumption and pollutants emissions. In 2010, China surpassed the United States as the world's largest energy consumer and greenhouse gases emitter [2]. Accordingly, several targets for reducing energy intensity by 16%, SO_2 emissions by 8%, and CO_2 emission intensity by 17% compared to their levels of 2010 by 2015 were set in China's 12th Five-Year Plan. Moreover, China has committed to bring its CO_2 emissions to a peak around 2030 and reduce its CO_2 emission intensity per unit GDP (gross domestic production) by 40–45% in 2020 and by 60–65% in 2030 compared to the 2005 level. However, achieving energy saving and improving the environmental performance are costly, meaning that there is

* Corresponding author.
E-mail address: yanglin0413@hotmail.com (L. Yang).

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commonly a trade-off between resource input, satisfying outputs, such as GDP, and unsatisfying outputs, such as pollutants emitted, under the current technological condition [3]. Given the fixed amount of resources, the more resources are diverted to pollution abatement activities, the less they are available for producing satisfying outputs and achieving energy saving [1]. Marginal abatement cost (MAC) derived from the directional distance function approach can be interpreted as the opportunity cost of reducing one additional unit of pollutant emission with regard to corresponding more use of inputs or less production of satisfying outputs [4,5]. Although the MAC is not an excellent indicator to assess climate policy [6], the estimation of MAC is capable of providing a reference for policymakers to design more effective energy and environmental policies, such as environmental taxation and emission trading systems [7,8].

The distance function approach, originally proposed by Shephard [9] and developed by Färe et al. [7], is considered as an appropriate metric for estimating the efficiency, as well as approximating the MACs of unsatisfying outputs using the concept of shadow price [10,11]. Generally, nonparametric or parametric technique can be applied to estimate the distance function and MACs (shadow price) [12]. The former does not assume a functional form for the underlying technology during the estimation, while the latter does.

Data envelopment analysis (DEA) is a widely used nonparametric method which estimates the distance function and MACs from a more aggregated perspective [13]. Some studies have applied this method to estimate the production efficiency and the MACs of various pollutants for the electric power plants in developed countries [14–18]. Some other studies used this method to analyze the total-factor efficiency and MACs of pollutants in China [19–24]. However, the production frontier estimated by the DEA method is not differentiable. In addition, the estimated results are sensitive to the outliers, which may directly influence the veracity of the results [25–28]. Therefore, DEA is not a suitable way to estimate shadow prices of pollutants [10].

Apart from DEA, the parametrical method is more appropriate to derive the distance function and pollutants' MACs (shadow prices). To date, three kinds of parametrical distance functions– i.e. Shephard input/output distance functions and directional output distance function (DODF) have been widely adopted. The parametric Shephard distance functions confines itself to the case of asymmetric change for satisfying and unsatisfying outputs. By contrast, DODF is more widely adopted due to non-proportional changes of satisfying and unsatisfying outputs. Using the parametric method, a functional form[1] is firstly specified for the distance function and then the related parameters of this function can be estimated by mathematical programing [24]. The values of distance function and shadow price are calculated based on the estimated parameters.

The parametric method has been used to estimate various distance functions. Färe et al. [7], Coggins and Swinton [29] and Cuesta et al., [30] used the Shephard output distance function to parametrically estimate the shadow prices of pollutants for pulp and paper industry, coal-burning power plants, electricity enterprises, respectively. Hailu and Veeman [4], as well as Tang et al. [31] applied the Shephard input distance function to parametrically evaluate the production technical efficiency and shadow prices of pollutants for the Canadian pulp and paper industry and Australian broadacre farming. Some studies used the quadratic DODF to estimate the shadow price of different pollutants for the electric power sectors of India, Korea, Japan, and Unite states, respectively [10,18,32–34]. Some other studies also used the quadratic DODF to analyze the efficiency and CO_2 shadow price for China's thermal power enterprises [26], different provinces [27,35] and industrial sectors [36–38].

Nevertheless, all the aforementioned parametric approaches have limitations. The Shephard input distance function cannot be adopted when considering the bad outputs; the Shephard output distance function expands the satisfying and unsatisfying outputs proportionally. Therefore, both of them are not appropriate for performance evaluation when bad outputs are subject to outside regulation [24]. Regarding the parameterized DODF, it overlooks the input dimension, not allowing the simultaneous increase in satisfying outputs and reduction in resource input and unsatisfying outputs. Leleu [39] pointed out that using the DODF is not sufficient enough to guarantee the appropriate shadow price of unsatisfying outputs, though it is a sufficient way to estimate technical efficiency. To the best of our knowledge, there is no study that has used a parametric distance function approach which simultaneously considers the energy saving and pollution reducing to estimate the total factor efficiency and pollutants' MACs in developing countries.

This paper is the first study to estimate the provincial total factor efficiency and pollutants' MACs in China using a parameterized non-radial directional distance function (DDF) which captures the advantages of differentiability and simultaneous increase in satisfying outputs and reduction in resource inputs and pollutants emissions. The differentiability guarantees the uniqueness of production efficiency and MAC, while the simultaneous changes imply the "triple-dividend" of economic production activities, energy saving, and pollution abatement [27,28]. Considering China's regional diversity in economic, social, and resource endowments, it is therefore necessary to estimate the relevant parameters at regional level. We hope the estimated results can help design and optimize energy saving and pollution abatement policies in developing countries like China.

The article consists of five sections, including this introduction. Section 2 presents the parametric methods used in our analysis. Section 3 explains the regional panel data employed in the empirical study. Section 4 provides the main results and discussion. Section 5 summarizes the conclusions.

2. Methodology

2.1. A generalised non-radial directional distance function

In production activities, using inputs, such as energy, to produce of "satisfying" outputs, such as GDP, commonly comes with the production of unsatisfying by-products, such as CO_2 or SO_2. Here we consider a production process producing good outputs $y = (y_1, \ldots, y_n) \in R_+^N$ and bad outputs $b = (b_1, \ldots, b_j) \in R_+^J$ by utilising inputs $x = (x_1, \ldots, x_m) \in R_+^M$. Then we can define the production possibilities by the set $T \subset R_+^M \times R_+^N \times R_+^J$ where:

$$T = \{(x, y, b) : \ x \ \text{ can produce } (y, b)\}. \tag{1}$$

T is first assumed as a convex compact set. In addition, satisfying outputs' free disposability, inputs' strong disposability, no free lunch, and inaction possibility are assumed based on [9] (see also Grosskopf [40]).

In addition, the notion that the technology is null-jointness is modelled by

$$\text{If } (y, b) \in T \text{ and } b = 0 \text{ then } y = 0, \tag{2}$$

which implies the satisfying or desirable outputs are "null-joint" with the unsatisfying or undesirable outputs and the only way to produce zero bad outputs is that no good outputs are produced.

[1] In empirical analysis, the Shepherd distance functions are usually specified as a translog functional form, while the directional distance function is usually specified as a quadratic functional form.