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Exploring shadow prices of carbon emissions at provincial levels in China

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ABSTRACT

Since carbon emissions are considered to contribute the lion's share in global warming, extensive studies have been devoted to measuring the carbon emissions abatement cost in various ways. This paper derives the shadow prices of China's aggregate carbon emissions at provincial levels by using directional output distance function and Shephard output distance function. The empirical results indicate that the shadow prices estimated by the directional distance function with directional vector of (1,−1) are significantly higher than those estimated by Shephard distance function, which implies that the green production technology is very expensive for the developing country of China. In addition, the shadow prices of carbon emissions present a rising trend during the sample period, which implies that it is increasingly costly for China to regulate CO_2 emissions. Moreover, the shadow price is positively correlated with regional economic development levels. Generally, the shadow price of the high income regions is significantly bigger than that of low income regions. Therefore, China should promote regional scheme of carbon emissions reduction, such as regional carbon emissions trading scheme, to fulfill its ambitious target of carbon emissions reductions.

1. Introduction

Since 1970, global ecological footprint has exceeded biocapacity and the discrepancy between the two has increasingly enlarged. Carbon footprint is the largest individual component of global ecological footprint, and carbon emission reduction has been a highlight of the world. China has been the largest carbon emitter in the world since 2007 and the biggest energy consumer since 2010. In 2008, although China's per person ecological footprint was just 80% of the global average, China has the largest ecological footprint in the world due to its huge population size. Motivated by the fact, this paper estimates the cost of carbon emissions reduction at provincial levels in China since China features a significantly differentiated development mechanism in various regions. Understanding differences across regions can help to identify the factors influencing supply and demand of ecological services in China and allow efficient measures for limiting the growth of China's carbon footprint to be developed.

However, carbon emissions reduction is not free, and it may be expensive for some countries. Extensive studies have been conducted to measure the costs of carbon emissions reduction. Since undesirable outputs like carbon dioxide are non-marketable and cannot be reasonably priced in accordance with general commodities, the costs to reduce carbon emissions have not been included in the accounting system. It is not beneficial to the regulation of factories' discharges or the implementation of emission-cutting policies. Shadow prices, or the marginal abatement costs of undesirable outputs, which can be interpreted as the opportunity cost of reducing an additional unit of undesirable output in terms of forgoing desirable output, are introduced to price the undesirable outputs properly. Cost function and distance function are the two commonly used methods to estimate the marginal abatement costs of undesirable outputs. Cost function can provide information about the relation between the marginal abatement costs of pollutants and actual emission levels under the assumption concerning cost minimization. However, the assumption of cost-minimizing behavior, which is essential in this method, limits its empirical application since this assumption is improper for the cases where the actions of the parties involved have some public aspects. Distance function, originally introduced by Shephard (1970) and applied by Färe et al. (1993) in empirical fields, has advantages over the cost function method. A distance function requires no behavioral assumptions concerning cost minimization or revenue maximization (Kumbhakar and Lovell, 2000).

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In addition, information on output and input prices or regulatory constraints are not required in a distance function framework (the price data of pollutants are usually unavailable). Therefore, the distance function method has been broadly employed to estimate the shadow prices of undesirable outputs.

Generally, a distance function can be estimated in two different ways, i.e., the nonparametric data envelopment analysis (DEA) and parametric approach. The advantage of the DEA is that it does not require the specific functional form for the technology. It has been used in various contexts in which undesirable outputs are present. For example, taking the thermal power sector of China as a case, Kaneko et al. (2010) discussed the marginal abatement costs of SO_2. Choi et al. (2012) employed the slacks-based DEA model to estimate the marginal abatement costs of CO_2 emissions for China's 30 provinces during 2001–2010. However, the DEA is based on a piece-wise linear production frontier that is not differentiable and, hence, its principle disadvantage is that it may be problematic to obtain the relevant abatement costs information.

Two primary parametric approaches have been used to estimate the marginal abatement costs in distance function framework. The first parametric approach uses econometric estimation to determine the best-fit distance function (e.g., Lovell et al., 1994; Grosskopf et al., 1997). The principle advantage of this technique is that it is better able to accommodate measurement or other random error and allows for hypothesis testing. However, Coelli and Perelman (1999) indicated that this approach limits the researcher's ability to apply a priori inequality restrictions on the distance function, a procedure that is easily accomplished with the deterministic approach. As a result, this technique is the most commonly used when all outputs are considered beneficial.

The second parametric deterministic approach is originated by Färe et al. (1993) in which the distance function is estimated by using an Aigner and Chu (1968) linear program. Färe and Grosskopf (1998) indicated that this technique is the most common approach of the three primary approaches used to estimate marginal abatement costs in a distance function framework. The advantage of this technique is that the distance function is given a specific differentiable functional form, usually a translog due to its particular flexibility. And it has been widely used in various contexts in which undesirable outputs are present. For example, Lee (2005) estimated shadow prices of SO_2 with data from coal-fired US power units operating between 1977 and 1986. Hu et al. (2008) found the marginal abatement cost of SO_2 in western areas of China is the highest and that of central areas is the lowest. The directional output distance function appeals to the environmental policies because it allows the expansion of desirable outputs and the reduction of undesirable outputs simultaneously. Correspondingly, the quadratic functional form is usually employed to parameterize the directional output distance function, for the former allows restrictions required by the translation property and experts in the second-order approximation of unknown distance functions. Based on the directional/quadratic method, Matsushita and Yamane (2012) derived shadow prices of CO_2 and low-level waste in the case of the electric power sector in Japan.

Following this line of research, this paper derives shadow prices of CO_2 emissions at China's provincial levels. China has set an ambitious target of CO_2 emission intensity reduction during the 11th Five-Year Plan period (2006–2010), and therefore this period is taken as the sample. Compared with the nonparametric method, the parametric approach has the advantage of providing an estimated parametric representation of the true production technology that is everywhere differentiable. The very feature implies shadow prices can be defined through the assumption the observed price of one desirable output equals its shadow price (Kwon and Yun, 1999). Moreover, we can introduce time trend in parametric approach to capture the effect of neutral technical change. In addition, both Shephard distance function and the directional distance function are used to explore shadow price of carbon emissions in this paper, which can measure the shadow prices of carbon emissions in different production technologies and provide more insights for policy makers. Shephard output distance function considers the maximal possible proportional expansions onto the boundary of production technology about the observed desirable and undesirable outputs, which is relatively complied with the current production technology. In addition, this paper uses the directional output distance function to estimate shadow prices of pollutants by choosing the directional vector $g = (1,-1)$. This setting will credit the production units for simultaneously expanding good output and contracting bad output production with constant input. Due to this, the results of shadow prices measured by this approach might be respectively high (Vardanyan and Noh, 2006; Choi et al., 2012). To some extent, the shadow price of carbon emissions estimated by directional function may represent the cost of using green production technology which requires reduction in bad outputs.

The remainder of this paper is organized as follows. Section 2 mainly introduces the directional output distance function and derives two shadow price models. Section 3 presents the empirical results of shadow prices of CO_2 emissions. Section 4 discusses empirical results and provides some policy implications in emissions reductions. The final conclusions are summarized in Section 5.

2. Methods

A common feature of Shephard distance function is that they assume the maximal possible proportional expansions onto the boundary of production technology about the observed desirable and undesirable outputs. However, the directional output distance function can expand desirable outputs and contract undesirable outputs simultaneously by choosing a particular direction vector. In fact, the directional output distance function is a generalization of the Shephard output distance function, or the latter is a special case of the former (Färe et al., 2006).

2.1. The directional output distance function

In fact, the directional output distance function is a functional representation of the production technology. The production units employ inputs (x) to produce good (desirable) outputs (y) and bad (undesirable) outputs (b). The production technology is expressed as $P(x) = \{(y, b){:}\ x \text{ can produce } (y, b)\}$. In line with Chung and Färe (1995) and Färe et al. (2006), we specify the production technology by imposing some assumptions. $P(x)$ is a compact set with $P(0) = \{0,0\}$ and inputs are strongly or freely disposable.

We define $g = (g_y, g_b)$ as the direction vector, and assume $g \neq 0$. The directional output distance function can be described as

$$\vec{D}_0(x, y, b; g_y, g_b) = \max\left\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\right\}, \tag{1}$$

The function denotes that the simultaneous maximum reduction in bad outputs and expansion in good outputs are feasible in a given production technology. As illustrated in Fig. 1, the production unit $A = (b,y)$ can expand y and contract b along the g_1 direction until it reaches the boundary of $P(x)$ at the point $A1 = (b - \beta^* g_b, y + \beta^* g_y)$, where, $\beta^* = \vec{D}_0(x, y, b; g)$.

The distance function takes the value of zero for technically efficient outputs on the boundary of $P(x)$, while positive values suggest inefficient outputs inside the boundary. Corresponding to homogeneity of the standard Shephard output distance function, the