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Marginal CO_2 abatement costs: Findings from alternative shadow price estimates for Shanghai industrial sectors

X. Zhou [a], L.W. Fan [b], P. Zhou [a,*]

[a] College of Economics and Management & Research Centre for Soft Energy Science, Nanjing University of Aeronautics and Astronautics, 29 Jiangjun Avenue, Nanjing 211106, China
[b] Business School, Hohai University, 8 Focheng West Road, Nanjing 211100, China

HIGHLIGHTS

- We estimate the shadow prices of CO_2 emissions for Shanghai's manufacturing sectors.
- Multiple distance function approaches are employed in the empirical analysis.
- Model selection indeed has a significant effect on the shadow price estimation.
- The CO_2 shadow price and the carbon intensity have a negative relationship.

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ABSTRACT

Shanghai, one of the most developed cities in China, is implementing a pilot regional carbon emission trading scheme. Estimating the marginal abatement costs of CO_2 emissions for the industrial sectors covered in Shanghai's emission trading scheme provides the government and participating firms useful information for devising compliance policies. This paper employs multiple distance function approaches to estimating the shadow prices of CO_2 emissions for Shanghai industrial sectors. Our empirical results show that the overall weighted average of shadow price estimates by different approaches ranges between 394.5 and 1906.1 Yuan/ton, which indicates that model choice truly has a significant effect on the shadow price estimation. We have also identified a negative relationship between the shadow price of CO_2 emissions and carbon intensity, and the heavy industries with higher carbon intensities tend to have lower shadow prices. It has been suggested that Shanghai municipal government take various measures to improve its carbon market, e.g. using the marginal abatement costs of participating sectors/firms as a criterion in the initial allocation of carbon emission allowances.

1. Introduction

1.1. Background

International communities call for concerted efforts in reducing global carbon dioxide (CO_2) emissions in order to mitigate the global warming. As one of the major CO_2 emitters, China made a commitment in 2009 to decrease its CO_2 emissions per unit of GDP (i.e. carbon intensity) by 40–45% by 2020 with 2005 as the reference year. Later, the central government of China has explicitly set the target of reducing carbon intensity by 17% till 2015 compared to that in 2010. Various policies have been taken to achieve the national emission reduction targets, among which emission trading has been identified as an important cost-effective policy instrument. Since 2013, seven pilot provinces and provincial cities, i.e. Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Chongqing and Hubei, have successively launched their emission trading schemes (ETS). These regional pilot carbon markets are regarded as indispensable experiments before establishing a nation-wide ETS in China. In this context, it is of policy and managerial significance to conduct relevant studies on the emerging ETS in China. The issues of policy boundary, e.g. cap setting, allowance allocation, monitoring, reporting and verification system, registry, carbon leakage and cost-effectiveness evaluation, have attracted much attention from researchers (Chang and Wang, 2010; Yi et al., 2011; Zhou et al., 2013; Jiang et al., 2014; Wu et al., 2014; Zhang et al., 2014a,2014b). These earlier studies, which were mainly conducted from the perspective of system design, provide policy

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[*] Corresponding author. Fax: +86 25 84892751. ,
E-mail addresses: nuaa_zhouxun@163.com (X. Zhou), rocy_zhou@hotmail.com (P. Zhou).

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makers useful suggestions for the development of China's ETS. This paper, however, aims to examine another key issue relevant to China's ETS, i.e. the marginal abatement costs of CO_2 emissions. Estimating marginal abatement costs of CO_2 emissions for the industrial sectors covered in China's regional pilot emission trading schemes can provide valuable information to local governments and participating firms for improving the operating rules of ETS and devising carbon abatement strategies. In this paper, we shall take the regional pilot ETS in Shanghai as a case for estimating the marginal abatement costs (MACs) of CO_2 emissions for the industrial sectors covered by multiple shadow-pricing approaches.

Shanghai is one of the largest and the most developed cities, with a resident population of 23.5 million, GDP of 1.9 trillion Yuan, and total energy consumption of 112.7 million tons of coal equivalent (TCE) in 2011 (Shanghai Municipal Statistics Bureau, 2010–2012a, 2010–2012b). Its regional pilot ETS, hereafter referred to as SH–ETS, started on November 27, 2013. Till June 2014, the overall trading volume in SH–ETS has reached 1.55 million tons with total trading value of 60.92 million Yuan. The SH–ETS follows three fundamental principles, i.e. reducing carbon abatement costs through a government guided market system, aiming at controlling carbon intensity, and focusing on industries with high carbon emissions or emission intensities. The participating firms are those belonging to the category of industries including steel and iron, petrochemical, chemical, nonferrous metal, electric power, building material, textile, paper, rubber and chemical fiber with direct and indirect CO_2 emissions not less than 20,000 t in 2010/2011. In addition, firms in the tertiary sectors such as airlines, port, airport, railway, commerce, hotel and financial sectors, with direct and indirect CO_2 emissions not less than 10,000 t during 2010–2011, are also covered in the scheme. At the first stage, free emission allowances (denoted as SHEAs) for 2013–2015 were assigned to a total of 197 firms at one time based on their CO_2 emissions in 2009–2011. The allocation process considered several factors such as reasonable growth of production volume, energy conservation and emission reduction activities previously adopted, and the discrepancy in the stage of industrial development.

In the operation of SH–ETS, a realistic question comes out: How will the participating firms fulfill their obligations in a cost-effective way? Firm managers will deliberately utilize quantitative information to rationalize their decision making and devise the best abatement strategies. The market price of SHEA and the marginal abatement cost (MAC) of CO_2 emissions are certainly the information they need. Through comparing market price of SHEA with MAC, firm managers can make more reasonable business decisions by screening a list of candidate policy options, e.g. business as usual, carbon abatement by technological investment, buying SHEAs, selling SHEAs, and reserving redundant SHEAs. From the perspective of government, a good understanding of MACs could help Shanghai government formulate more appropriate carbon abatement policies, e.g. the estimated MACs may be used as a reference for carbon pricing through emission allowance allocation. Only by rational pricing can the SH–ETS transfer the carbon abatement tasks from the production units with higher MACs to the ones with lower MACs.

1.2. Review of MAC estimation methods

Alternative methods such as cost-benefit analysis, dynamic optimization model, input–output analysis, computational general equilibrium model, integrated assessment model and distance function approach, have been used to estimate the MACs of CO_2 emissions. The study by Zhang and Folmer (1998) provided an excellent review of alternative economic approaches to evaluating carbon abatement costs. In application, Chen (2005) estimated the MACs of CO_2 emissions under a set of carbon abatement policy scenarios for China with MARKAL–MACRO model, a hybrid model integrating the widely used energy-sector optimization model named MARKAL and a macroeconomic model named MACRO. Klepper and Peterson (2006) applied computational general equilibrium model to drive the MAC curve of CO_2 emissions by considering the relationship between global abatement level and energy price. Simões et al. (2008) employed a dynamic optimization model named TIMES_PT to derive the MAC curves under different carbon abatement scenarios for the Portuguese energy sector. These estimation methods focus on MACs that occur in an abatement project, energy sector, a country or even the world.

In contrast, the distance function approach proposed by Färe et al. (1993, 2005) approximates the MACs by using the concept of shadow price. The shadow price of CO_2 emissions may be interpreted as the opportunity cost of an incremental CO_2 reduction in terms of forgone good outputs in a production process. In estimating shadow price, the distance function approach mainly uses the quantities of inputs and outputs of production units, which indicates that its data requirement is relatively modest. Additionally, the distance function approach is very flexible in the level of application, which can be applied to the cases of firms, sectors or even regions (Boyd et al., 1996; Coggins and Swinton, 1996; Lee et al., 2014; Zhou et al., 2014b).[1]

In methodology, the distance function approach may be regarded as an analytical framework consisting of a family of models. The shadow prices of undesirable outputs are derived from the duality relationship between distance function and revenue, cost or profit function, and distance function provides a characterization of technological relationship between inputs and outputs (Färe and Grosskopf, 2000). Either parametric or nonparametric efficiency model can then be used to evaluate the distance function and compute the shadow price (Zhou et al., 2014b). Along this line of thought, Färe et al. (1993) first provided a formula for deriving the shadow prices of undesirable outputs by using a translog Shephard output distance function to characterize environmental production technology. Turner (1994) developed a sub-vector Shephard output distance function to construct the production frontier and employs data envelopment analysis (DEA) to estimate the pollution abatement cost. Boyd et al. (1996) combined directional distance function (DDF) and DEA to estimate the shadow price. Hailu and Veeman (2000) employed the translog Shephard input distance function and a deterministic parametric approach to computing the shadow price. Lee et al. (2002) extended the shadow-pricing approach by Boyd et al. (1996) by considering inefficiency factors. Boyd et al. (2002) provided an alternative procedure for estimating shadow price through two different DEA models. Färe et al. (2005) applied a quadratic DDF to estimate the shadow price via both deterministic and stochastic parametric computational methods. Vardanyan and Noh (2006) conducted a comparison between different parametric shadow-pricing models and pointed out that model choice had a significant impact on the shadow price estimates.[2] Leleu (2013) introduced a hybrid DEA model to solve a set of methodological debates in nonparametric shadow-pricing approaches. Rødseth (2013) constructed a novel DDF model that considers various pollution reduction options to identify the least-costly abatement strategy for decision makers. Lee et al. (2014) proposed an integrated

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[1] See Rødseth (2013), Lee et al. (2014) and Zhou et al. (2014b) for discussions on the weaknesses of distance functions in estimating the MACs of undesirable outputs.

[2] Compared to Vardanyan and Noh (2006), this study considers not only output-based parametric models but also input-oriented nonparametric shadow-pricing models, which could provide a more complete picture on the differences between alternative models.