Energy Economics 46 (2014) 66–77

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

A new approach to measuring shadow price: Reconciling engineering and economic perspectives

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ARTICLE INFO

Article history:
Received 18 September 2012
Received in revised form 21 July 2014
Accepted 29 July 2014
Available online 12 August 2014

JEL classification:
C61
Q53

Keywords:
Shadow price
Undesirable outputs
Carbon abatement
Power plants

ABSTRACT

Shadow price is one of the most important pieces of information in environmental decision making. Two different approaches—namely, economic and engineering—have been applied to obtain the shadow price of undesirable outputs, while using different methodological backgrounds and perspectives. The current study proposes a new conceptual framework and an economic estimation model to reconcile the shadow price estimates derived via the two approaches. We also suggest a new mapping rule that incorporates the concept of abatement level, which is a basic element in the engineering approach. As a result, the proposed model generates continuously changing estimates—i.e., comprising a shadow price curve—based on the abatement level. We further investigate the determinant factors of shadow price by using second-step regression. The suggested methodology is used to investigate the shadow price of carbon emissions in South Korean electricity generating plants, thus yielding relevant policy implications.

1. Introduction

Both the importance and awareness of carbon abatement has continuously increased, despite prevalent arguments about the prospects of international efforts to mitigate climate change, most of which arise from political and economic interests. Various eco-friendly policies and guidelines have been developed by governments, with the aim of reducing carbon emissions. Typical examples of such policies in the electric power industry include the regulation of the increased use of green energies (e.g., Renewable Portfolio Standards), the activation of carbon trading markets, and the development of clean and intelligent technologies (e.g., Smart Grid).

The pressure to apply carbon abatements has expanded from the national or industrial-sector level to the level of individual companies and buildings, in order to fulfill government objectives or self-imposed goals. In particular, enhancements in eco-efficiency are thought to constitute one of the key factors behind the existence and sustainable development of enterprises in the changing business environment. New decisions that consider low carbon emissions are required, if a company is to enhance its competitiveness in the market and acquire new business opportunities when managers set product portfolios and business strategies. Companies in energy-intensive industries would be confronted with a severe business environment, if they were to have problems coping with carbon-related issues, in the absence of appropriate decision making and preemptive responses.

As Coelli et al. (2007) and Murty and Kumar (2002) argue, the options for carbon abatements among production units can be categorized into several different fields, including those that address the development and adoption of abatement technologies, the enhancement of technological efficiency, increases in environmental allocative efficiency, investments in emission reduction facilities, decreases in production, and the trade of emission credits across production units. For example, electricity generating plants can embrace technological options, such as the increased use of clean fuels, enhancements to electricity generating processes, and investments in carbon-capturing and sequestration systems (Jorgenson and Wilcoxen, 1990; Sims et al., 2003). In line with such trends, the carbon abatement activities of production units have increased, particularly with regard to data aggregation vis-à-vis carbon emissions and the construction of data management systems. The amount of carbon abatements, the total abatement cost, and the marginal abatement cost of carbon emissions are factors typically captured within a carbon-related dataset.

Since there are usually no generalized market prices with respect to undesirable outputs, the evaluation of undesirable outputs is commonly considered difficult. It is particularly problematic, as Pittman (1983)

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http://dx.doi.org/10.1016/j.eneco.2014.07.019
0140-9883/

points out, in cases when there are no appropriate estimation methods for examining some production units. Nonetheless, there have been two main approaches to estimating the value of undesirable outputs: engineering and economic approaches. These two approaches have been developed and proposed by the quite-different disciplines of environmental engineering and economics. These approaches have chosen distinct research strands, in some aspects. First, the two approaches use different databases and methodologies. Second, the engineering approach takes technological perspectives, whereas economic estimations consider the entire production process. The former is essentially based on information pertaining to the cost of implementing abatement technologies, while the latter includes the overall cost factors that a producer should bear. The shadow price in the economic approach can be considered synonymous with the marginal abatement cost (MAC) within the engineering approach, which is incurred when reducing one unit of carbon emissions.

Although the two approaches share a common focal point—i.e., they mainly measure the potential MAC of a specific unit—the aforementioned differences mean that the results of one approach are rarely cited by the other. Since the estimates of the two approaches are often quite different in their features, decision makers are subject to confusion when reviewing them. Moreover, results stemming from the engineering approach have rarely been compared to or combined with those stemming from the economic approach. To the best of the authors' knowledge, Boyd et al. (1996) is the only study to attempt empirically a comparison of one approach with the other in evaluating the sulfur dioxide (SO_2) emissions of coal-fired power plants. To fill this research gap, the current study suggests a methodology that can reconcile the engineering and economic approaches; specifically, it argues that these approaches are not contradictory, but rather complementary.

The suggested methodology is employed to examine the shadow price of carbon emissions in South Korea's electricity power plants during the period 2004–08. The empirical results indicate that (i) shadow price increases gradually with the carbon dioxide (CO_2) abatement target level, (ii) shadow price varies largely across fuel types, and (iii) shadow price increased over the study period, on average.

The remainder of this paper is organized as follows. The next section reviews the two different measurement approaches. Section 3 summarizes previous economic estimation studies and addresses common issues with respect to shadow pricing models; we then describe our new scheme and our estimation model for shadow pricing, in Section 4. Section 5 describes the dataset and discusses the empirical results. Section 6 briefly concludes our study and highlights relevant policy implications.

2. Engineering and economic approaches

2.1. Engineering approach

The engineering cost (i.e., in this study, MAC) is the cost incurred by a producer in reducing undesirable outputs by one unit. It usually comprises investments and expenditures related to reduction technologies. MAC is estimated by dividing the total abatement cost by the available amount of reduction. The engineering approach uses information containing detailed descriptions regarding alternative technologies or activities for reducing undesirable products. The expected reduction and its corresponding cost with respect to each technology constitute the overall abatement cost information.

The engineering approach stacks up different options by ordering the MAC, thus yielding a step-wise marginal cost curve. It breaks down the existing strategies into several individual abatement options, and prioritizes the activities with definite technological methods by which to meet the target reduction level in a particular target year. The engineering approach focuses on the technological aspects and potential for abatement in the target year. It is frequently used when developing strategies in the management and consulting areas, because it provides information by which one can obtain intuitive understanding and practical applications.

Fig. 1 depicts a typical outcome of the engineering approach, where horizontal and vertical axes represent the carbon emission reductions and the MAC, respectively. The step-wise solid line represents the MAC of carbon abatements, which comprises various technological options. As can be seen in Fig. 1, it is very common to observe an increasing trend in the MAC, because the options are ordered by the MAC. Therefore, the leftmost options could be the first choices of reduction activities. For comparative purposes, the options can be compared to others, in order to choose the best ones on the basis of simulation scenarios. Any technological options with a non-positive cost will yield benefits that are greater than or equal to the input cost (for example, see Option 1 in Fig. 1). The MAC can be generalized by an increasing curve, as the dashed line in Fig. 1. In cases when multiple units with different abatement options are aggregated, the MAC is highly likely to yield a smoother line. The current study regards the generalized curved form as an engineering cost curve.

The cost curve of the engineering approach represents the basic relationships between an emission level and abatement cost. For example, the MAC might increase greatly as the target emission level increases. The cost curve is applied to strategic decision making on abatement activities. Managers choose the optimal level of internal and external abatement activities, using the engineering cost curve and the trading market prices. Fig. 2 depicts the MAC curves of two carbon-emitting units, A and B. In this figure, a market price (p) is represented as a horizontal dotted line. The optimal level of internal abatement activities is chosen at the crossing points of the market price and each of the MAC curves, where a and b are the choices for units A and B, respectively.

The characteristics of the engineering approach are summarized as follows: (i) the approach has an amount of abatement and a cost of abatement for each technological option, (ii) the approach yields increasing trends in order of abatement cost, where the cost information is set based on the abatement level that must be achieved, and (iii) the curve can be established by following the available options of units under analysis.

2.2. Economic approach

The economic approach differs from the engineering approach. Economic costs are estimated through economic models, while taking into account the entire production process, along with key input and output factors. The engineering approach is based on an established technological database of abatement options, whereas economic models use actual production behavior data (Aiken and Pasurka, 2003). Shadow price is

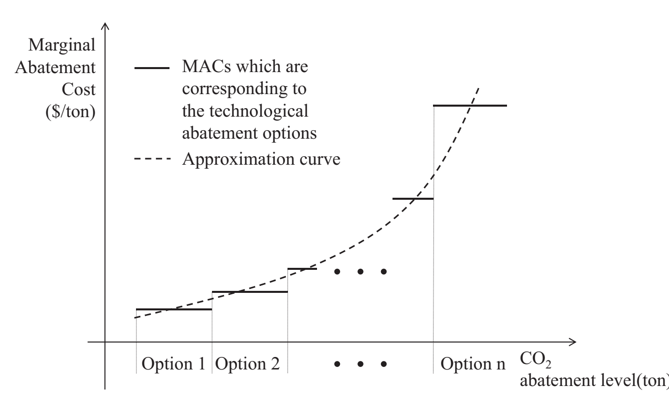

Fig. 1. MAC curve as engineering approach.