Energy Policy 39 (2011) 6162–6167

Contents lists available at ScienceDirect

Energy Policy

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

Potential cost savings from internal/external CO_2 emissions trading in the Korean electric power industry

Myunghun Lee *

Department of International Trade, Inha University, 253 Yonghyun-dong, Nam-gu, Incheon 402-751, Republic of Korea

ARTICLE INFO

Article history:
Received 13 August 2010
Accepted 10 July 2011
Available online 30 July 2011

Keywords:
CO_2 shadow price
Internal/External emissions trading
Cost-saving effect

ABSTRACT

Korea plans to introduce an emissions trading scheme for the controlling greenhouse gas emissions in 2015. Using Shephard's (1970) output distance function, we first estimate the shadow price of CO_2 for power generators in the Korean fossil-fueled electric generation industry. Then, by assuming that each power generator is required to reduce CO_2 emissions by one ton, we compute the potential cost savings from internal trading among generators within the same plant and from external trading across plants at prevailing market prices. The results indicate that, on average, the generators paid \$14.63 to abate one ton of CO_2 emissions in 2007. Plants realized additional gains through external trading. In particular, cost savings from trades between different fuel-fired plants were substantial.

1. Introduction

In 2010, the Korean government enacted the Framework Act on Low Carbon, Green Growth to pursue sustainable development and fulfill its responsibility in international society and announced its own mid-term mitigation goal to reduce GHG (greenhouse gas) emissions by 30% below BAU (business as usual) by 2020. Achieving this objective is challenging in that the Korean economy depends heavily on energy-intensive industries such as automobile manufacturing, shipbuilding, steel, and petrochemicals.

Korea's total primary energy consumption and CO_2 emissions amounted to 240 million tons of oil equivalent (TOE) and 501 million TOE, respectively, in 2008, both ranking ninth in the world. Korea's industrial sector accounted for 58.3% of total final energy consumption, followed by the transportation (19.8%) and residential/commercial (19.6%) sectors. The industrial sector depended mainly on petroleum (51.4%), followed by coal (23.6%) and electricity (15.7%) (Yearbook of Energy Statistics, 2010). Thus, minimizing the impact of GHG emission reductions on industries is crucial for the success of Korea's "low-carbon, green-growth" policy.

The emissions trading system, a market-based instrument for pollution control, makes it possible for firms to minimize their compliance costs. The government issues emission permits (i.e., pollution rights) to firms within the emissions target, and those emission permits can be traded among firms. High-cost firms are likely to buy permits from those who emit less if the market price is below the abatement cost. Hahn and Hester (1989) found that the U.S. saved up to \$13 billion in abatement costs by introducing its emissions trading system (authorized by the 1970 Clean Air Act).

The Framework Act on Low Carbon, Green Growth allows the government to use the cap-and-trade system to achieve its GHG emission reduction target. The Act on GHG Emissions Trading System of 2010 specifies the method for allocating emission allowances, the methods for registering/managing, and establishing/operating emission permit exchanges. The Act on GHG Emissions Trading System was amended in 2011 to reflect the needs of the industrial sector and will take effect in 2015. For the successful development and operation of this system, it is critical to carefully examine the extent to which emissions trading could help reduce abatement costs.

A number of studies have measured potential cost savings from taking economic incentive approaches. Atkinson and Lewis (1974) derived cost savings from particulate emissions reductions and the attainment of a certain level of ambient air quality in the St. Louis region using least-cost strategies. They found that the existing strategy was 10 times more expensive than the least-cost strategy. Hahn and Noll (1982) determined that 25 SO_2 pollution sources in the LA region would have saved \$10–\$23 million by emissions trading.

Many of these studies have assumed that economic incentives would result in least-cost outcomes. However, Atkinson and Tietenberg (1991) suggested that emissions trading systems would fail to achieve potential cost savings because of limitations imposed by real regulations. In addition, many studies have not taken into account the possibility that the regulatory cost impact may be influenced by the characteristics of production structures such as input substitutability. If fossil fuels and capital are

* Tel.: +82 32 860 7805; fax: +82 32 876 9328.
E-mail address: leemh@inha.ac.kr

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2011.07.016

strongly substitutable, then compliance costs may be lower than otherwise.

Therefore, it is desirable to estimate the production function or alternatively a dual cost function in capturing actual abatement costs. Perl and Dunbar (1982) showed that, on average, abatement costs for the power plant industry can be reduced by 36.6% by implementing SO_2 emissions trading. Gollop and Roberts (1985) suggested that regional SO_2 trading may enable power plants to reduce abatement costs by as much as 47%. These two studies took advantage of a dual cost function.

The present paper assumes that emissions trading is allowed among power plants emitting CO_2. For examining how market prices are determined and who buys or sells emission permits, it is necessary to investigate plants' cost structure for CO_2 abatement. Using Shephard's (1970) output distance function, we estimate the shadow price of CO_2, defined as the opportunity cost of abating one ton of CO_2 in terms of forgone electricity, for 11 fossil-fueled power plants (52 generators) in 2007. The distance function has two major advantages over the cost function—the maintained hypothesis of cost minimization is not imposed, and information on input prices and specific regulatory constraints are not required (Grosskopf et al., 1995; Lee, 2007). Thus, the distance function is suitable for studying Korean industries for which limited data are available. Then, by requiring each generator to reduce CO_2 emissions by one ton, we compute the potential cost savings from internal trading among generators within the same plant and from external trading across plants at prevailing market prices.[1]

The rest of this paper proceeds as follows. Section 2 defines the output distance function and derives the shadow price of CO_2. Section 3 presents the data and discusses the empirical results. Section 4 computes the gains from internal and external emissions trading, and Section 5 concludes.

2. The model

Consider a production technology for power plants that generate a vector of outputs $y \in \Re^2_+$ with a vector of inputs $x \in \Re^3_+$. The output vector contains electricity (q) and CO_2 (c) as a by-product of fuel, and input vector contains capital (k), labor (l), and fuel (f). The output set $G(x)$ includes all y that are technically feasible with x. Plants are not able to abate CO_2 emissions without any cost burdens. That is, they incur the opportunity cost of reduced electricity production resulting from the diversion of some inputs for emissions abatement efforts. In fact, cleaning up CO_2 emissions requires less fossil fuel consumption, and thus, plants invest in improving boiler fuel efficiency or increase their dependence on renewable sources such as hydroelectric, wind, photovoltaic, and nuclear power. As a result, we assume that the production technology satisfies the weak disposability of outputs, which implies that if $y \in G(x)$, then $\delta y \in G(x)$ for $\delta \in [0.1]$.

Following Färe et al. (1993) and Coggins and Swinton (1996), we introduce Shephard's (1970) output distance function defined over $G(x)$, which measures the maximal proportional inflation of y required to reach the technically efficient frontier of $G(x)$ with x unchanged:

$$O(x,y) = \inf\{\delta : (y/\delta) \in G(x)\}, \tag{1}$$

where $O(x, y) \le 1$ and $O(x, y)=1$ indicates that firms operate on the boundary of $G(x)$. Note that the distance function is homogeneous of degree 1 in y because increasing y with x fixed results in a proportional increase in the value of the distance function.

The revenue function is defined as the maximized revenue constrained to the value of the output distance function: $R(x,p) = \sup_y\{py : O(x,y) \le 1\}$, where $p \in \Re^2_+$ is a vector of output prices. Assuming that $G(x)$ is convex for x, a dual output distance function to the revenue function is derived as (Shephard, 1970)

$$O(x,y) = \sup_p\{py : R(x,p) \le 1\}. \tag{2}$$

Consider a Lagrangian function for the revenue maximization problem:

$$\Gamma = py + \mu(O(x,p) - 1).$$

The first-order conditions for y are

$$p = -\mu(x,p)\nabla_y O(x,p), \tag{3}$$

where ∇ is the partial differential operator. Färe et al. (1993) showed that $-\mu(x,p) = \Gamma = R(x,p)$ at the optimal point.

From (2), we have $O(x,y) \equiv p^*(x,y)\cdot y$, where p^* is the vector of revenue-maximizing output shadow prices. Differentiating with respect to y yields

$$\nabla_y O(x,y) = p^*(x,y). \tag{4}$$

Substituting (4) into (3) gives

$$p = R(x,p)p^*(x,y). \tag{5}$$

Provided that the market price of electricity, $p^0_q \in \Re^1_+$, equals its shadow price, we obtain from (5)

$$R(x,p) = p^0_q / p^*_q(x,y). \tag{6}$$

Employing (5), (4), and (6) sequentially, we can calculate the shadow price of CO_2, defined as the opportunity cost of abating one additional unit of CO_2 in terms of forgone electricity, as follows:

$$p_c = R(x,p)p^*_c(x,y) = R(x,p)(\partial O(x,y)/\partial c) = p^0_q \frac{\partial O(x,y)/\partial c}{\partial O(x,y)/\partial q}. \tag{7}$$

To obtain the marginal CO_2 abatement cost, which is given (7), we specify the output distance function in a translog functional form as follows:

$$\begin{aligned} \ln O(x,y) = {} & \alpha_0 + \sum_x \alpha_x \ln x + \sum_y \alpha_y \ln y + \tfrac{1}{2}\sum_x \sum_{x'} \gamma_{xx'} \ln x \ln x' \\ & + \tfrac{1}{2}\sum_y \sum_{y'} \gamma_{yy'} \ln y \ln y' + \sum_x \sum_y \beta_{xy} \ln x \ln y, \\ & x,x' = k,l,f, y,y' = q,c. \end{aligned} \tag{8}$$

Following Aigner and Chu (1968) and Färe et al. (1993), we use a linear programming technique to estimate (8). The constrained maximization is pursued as follows:

$$\begin{aligned} & Max \sum_j [\ln O(x^j,y^j) - \ln 1] \\ & s.t. \ln O(x^j,y^j) \le 0, \\ & \partial \ln O(x^j,y^j)/\partial \ln q^j \ge 0, \\ & \partial \ln O(x^j,y^j)/\partial \ln c^j \le 0, \\ & \sum_y \alpha_y = 1, \sum_{y'} \gamma_{yy'} = \sum_y \beta_{xy} = 0, \\ & \gamma_{xx'} = \gamma_{x'x}, \gamma_{yy'} = \gamma_{y'y}, \end{aligned} \tag{9}$$

where j indicates the observations; the objective function requires the minimization of deviations from the efficient boundary for individual observations, but the value in square bracket should be maximized because $O(x,y) \le 1$ implies that it takes zero or negative values; the first constraint indicates the range of values of the output distance function; the second and third ones correspond to the nonnegativity of shadow price of electricity and

[1] Swinton (2002) estimated the marginal SO_2 abatement costs for power plants by employing the output distance function and calculated the potential cost savings from the SO_2 allowance market by comparing the estimates with market prices.