Ecological Economics 69 (2010) 623–631

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Sulfur dioxide allowances: Trading and technological progress

Surender Kumar [a], Shunsuke Managi [b,*]

[a] Department of Policy Studies, TERI University, 10 Institutional Area, Vasant Kunj, New Delhi 110070, India
[b] Institute for Global Environmental Strategies, Japan

ARTICLE INFO

Article history:
Received 15 January 2009
Received in revised form 11 August 2009
Accepted 24 September 2009
Available online 19 October 2009

Keywords:
Sulfur dioxide allowances trading
Technological progress
Environmental policy
Distance function

ABSTRACT

The US Clean Air Act Amendments introduce an emissions trading system to regulate SO_2 emissions. This study finds that changes in SO_2 emissions prices are related to innovations induced by these amendments. We find that electricity-generating plants are able to increase electricity output and reduce emissions of SO_2 and NO_x from 1995 to 2007 due to the introduction of the allowance trading system. However, compared to the approximate 8% per year of exogenous technological progress, the induced effect is relatively small, and the contribution of the induced effect to overall technological progress is about 1–2%.

1. Introduction

Title IV of the 1990 Clean Air Act Amendments (1990 CAAA) introduces an emission permit trading system to regulate SO_2 emissions from US thermal power plants. The policy was implemented to reduce damage from acidification while achieving the lowest compliance costs.[1] The often-cited measure of the success of the program is that the market allowance prices were substantially lower than the marginal compliance costs initially predicted. The decline in compliance costs can be attributed to three factors: (i) a decline in fuel prices coupled with a reduction in rail transportation costs for low sulfur western coal, (ii) exogenous technological progress that would have occurred in the absence of the program, and (iii) the technological progress that has been ignited by the allowance trading program (Burtraw et al., 2005). Using a production frontier approach, this study disentangles these effects by estimating exogenous (i.e., the aggregate of (i) and (ii)) [2] and technological progress induced by the allowance system (i.e., (iii)) that occurred from 1995 to 2007.

Environmental policy is designed to enhance incentives for the development and utilization of environmentally friendly technologies beyond static efficiency (Kneese and Schulze, 1975; Managi et al., 2005; Akao and Managi, 2007).[3] Firms change their technology in various directions depending upon prices and costs, which may be influenced by environmental regulations. Several theoretical studies show the advantages of market-based instruments (MBIs) over command and control regulations for inducing technological progress.[4] Some recent studies have empirically examined the dynamic effects of environmental policy in the US electricity sector (Bellas, 1998; Keohane, 2002; Popp, 2003). Bellas (1998), for example, has found non-significant evidence of technological change in abatement regarding the installation of scrubbers. Keohane (2002) has found an increase in the adoption of new scrubber technology after the 1990 CAAA. Popp (2003) used patent data to measure the level of innovation. He found that while successful patent applications for flue gas desulfurization units were higher before the introduction of the 1990 CAAA, the post-1990 CAAA had more positive environmental effects. However, Lange and Bella (2005) find that while scrubbers installed under the 1990 CAAA are less expensive

* Corresponding author. Yokohama National University, 79-4, Tokiwadai, Hodogaya-ku, Yokohama 240-0067 Japan. Tel.: +81 45 339 3751; fax: +81 45 339 3707.
E-mail addresses: surenderkumarbansal@hotmail.com (S. Kumar), managi.s@gmail.com (S. Managi).

[1] The allowance trading program was divided in two phases. Phase I affected 110 of the dirtiest plants and remained operative from 1995 to 1999. Units in phase I could emit at a rate of 2.5 lb of SO_2 emissions per million British Thermal Units (mBTUs) of heat input. All other units of fossil-fueled power plants could annually emit at the rate of 1.2 lb of SO_2 emissions per mBTUs of heat input. Phase II has been in operation since January 2000. In this phase, all major plants can emit at a rate of 1.2 lb of SO_2 emissions per mBTUs of heat input. Under the emissions trading system, the firms have an incentive to find the lowest-cost means of achieving compliance and to reap financial rewards for developing these means. Some recent studies (Carlson et al., 2000; Swinton, 2004) empirically examine the cost effectiveness of allowance trading systems.

[2] Relative change in input or/and output prices causes substitution effect and thereby affects the compliance costs in addition to technological changes. We try to distinguish between the effects on compliance costs of the introduction of SO_2 trading and all other causes.

[3] "Over the long haul, perhaps the most important single criterion on which to judge environmental policies is the extent they spur new technology towards the efficient conservation of environmental quality" (van Soest, 2005, pp. 236).

[4] See Requate (2005) for a survey of theoretical literature on dynamic incentives provided by various environmental policy instruments. Jaffe et al. (2003) has reviewed the literature on environmental policy and technological change.

0921-8009/$ – see front matter
doi:10.1016/j.ecolecon.2009.09.013

to purchase and operate than older scrubbers, these cost reductions appear as a one-time drop rather than a continual decline.

Innovations under SO_2 allowance trading do not remain limited to scrubbing; rather, other abatement options, such as organizational changes at the firm, market, and regulatory level as well as process changes, are also allowed (Burtraw, 2000). Kolstad and Turnovsky (1998) and Considine and Larson (2006) showed that technological change has reduced the emissions of sulfur, thereby supporting the notion that technological progress has been responsible, at least in part, for the drop in the abatement costs of SO_2 emissions. Similarly, Carlson et al. (2000) found the approximate 20% declines in marginal abatement costs from 1985 to 1995 can be attributed to exogenous technological changes. However, these studies do not distinguish the technological progress that is exogenous (that is, technological progress that happened even in the absence of allowance trading) and the technological changes that were ignited by allowance trading. This study fills this void by decomposing the technological progress into exogenous and induced components so that the contribution of the allowance trading system can be explicitly recognized.

Technological change can be decompos1ed into two components: innovation and diffusion. The transformation function[5] is best suited to measure technological change (see Jaffe et al., 2003); it represents “best practice,” i.e., what an electricity-generating plant would produce if all innovations made to date had fully diffused. Therefore, a shift in the transformation function captures innovations. The role of diffusion would then arise if some plants are not adopting the “best practice” but rather operating at points inside the transformation frontier. The movement of these plants toward the frontier can be termed as a “catch-up” effect, technological diffusion, or efficiency change (EC).[6] This study extends the literature on induced technological progress by measuring both innovations and diffusion.

There is a considerable theoretical and empirical literature on the measurement of the induced innovation hypothesis.[7] That literature typically analyzes the induced effect in terms of conventional representations of production technology, such as costs, production, or profit functions. However, distinctions between factor or output substitution and shifts in production technology frontiers cannot be addressed by conventional representations. In conventional representations, when current and long-run prices appear along with input–output vectors, the comparative static relations of the stated price-induced innovation model do not follow traditional forms, because the direct derivatives of the demand and supply functions with respect to prices are unsigned, given the presence of the cross derivatives (Celikkol and Stefanou, 1999; Paris and Caputo, 2001). Moreover, the traditional measures of productivity do not account for the production of harmful by-products such as SO_2 emissions, which may lead to environmental damage. Some recent studies[8] have included environmental externalities and have found that these measures differ from traditional measures.

We use a directional output distance function as a representation of production technology in order to simultaneously expand good output and contract bad outputs. It is particularly well suited to measure technical efficiency in the input–output space and satisfies all the properties that are required by conventional representations.

We measure technological change (TC) for US thermal power plants from 1995 to 2007. TC is similar in nature to any investment process, as it requires time and adjustment that is not instantaneous, and the choice of technology is influenced by long-term prices. TC is decomposed into two parts, namely, exogenous technological change (ETC) and induced technological change (ITC). A time trend variable is used to measure exogenous innovation.[9] Similarly, the inclusion of long-term allowance prices, as a factor accounting for shifts in the transformation function, is used to measure the induced innovation effect.[10]

The paper is organized as follows. Section 2 outlines the theoretical structure of the study. Section 3 presents the empirical model for the stochastic estimation of directional output distance function, and the data are described in Section 4. Section 5 discusses the main results of the study, and conclusions are presented in Section 6.

2. Measurement of technological progress

2.1. The directional output distance function

Suppose that an electricity-generating plant employs a vector of inputs $x\in\Re_+^K$ to produce a vector of good outputs (e.g., electricity output) $y\in\Re_+^N$, and bad outputs $b\in\Re_+^N$ (e.g., SO_2 and NO_x) (see Managi and Kaneko, 2009). Let $P(x)$ be the feasible output set for a given input vector x. The technology set is defined as:

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

Production technology can be modeled in other ways. The output is strongly or freely disposable if $(y, b)\in P(x)$ and $(y', b')\leq(y, b)\Rightarrow(y', b')\in P(x)$. This implies that if an observed output vector is feasible, then any output vector smaller than that is also feasible. This assumption prevents production processes that generate poor outputs and are costly to dispose. For example, pollutants should not be considered to be freely disposable. In such cases, poor outputs are considered weakly disposable: $(y, b)\in P(x)$ and $0\leq\theta\leq1\Rightarrow(\theta y, \theta b)\in P(x)$. This implies that pollution is costly to dispose and that abatement activities typically divert resources away from the production of desirable outputs, thus leading to lower desirable outputs given the inputs. Moreover, desirable outputs are assumed to be null-joint with the undesirable outputs.[11] Formally, the directional output distance function is defined as:

$$D(x, y, b; g) = \max_{\beta}\{\beta : (y + \beta\cdot g_y, b - \beta\cdot g_b)\in P(x)\} \tag{2}$$

This function requires a simultaneous reduction in pollutants and expansion in electricity output. The computed value of β, β^* provides the maximum expansion of electricity production and the maximum contraction of pollutants if a firm is to operate efficiently given the directional vector g. The vector $g=(g_y-g_b)$ specifies the direction an output vector (y,b) $P(x)$ is scaled so as to reach the output boundary set at point $(y+\beta^*\cdot g_y, b-\beta^*\cdot g_b)$ $P(x)$ by expanding electricity production and contracting pollutants, where $\beta^*=D(x, y, b; g)$.

The directional output distance function derives its properties from the output possibility set P(x) (Färe et al., 2005, 2007). These properties include monotonicity conditions for desirable and poor outputs as well as a translation property, which is the additive

[5] The transformation function describes a frontier of production possibility, that is, a set of combinations of inputs and outputs that is technically feasible at a point in time.

[6] The directional distance function constitutes a transformation function by using the data of the countries under study. Thus, it is a relative measure of technical inefficiency across countries. It can identify the practices adopted by the most efficient country that are diffused to other countries. This is not equivalent to saying that most efficient country uses only the latest innovations, i.e., directional distance function cannot say anything about diffusion within a country.

[7] See Hayami and Ruttan (1971), Binswanger (1974, 1978), and Thirtle and Ruttan (1987) for a literature review.

[8] See, for example, Hailu and Veeman (2001); Färe et al. (2005), and Kumar (2006).

[9] Technological progress occurs due to both inducements and advancements in general science and technology. Therefore, a time trend is included to account for the impact of scientific innovation on production technology (Lansink et al., 2000, pp. 500, footnote 1).

[10] The notion that long-run prices may serve as a stimulating factor for innovation is a critical component of the price-induced innovation model. Changes in current prices induce factor substitution, whereas changes in long-run prices induce the development of new technologies and may lead to shifts in the technology frontier.

[11] Null-jointness implies that a firm cannot produce desirable outputs in the absence of undesirable outputs, i.e., if $(y, b)\in P(x)$ and $b=0$ then $y=0$.