



A dynamic approach to environmental compliance decisions in U.S. Electricity Market: The Acid Rain Program revisited



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ARTICLE INFO

JEL classification:

L94
D92
Q52

Keywords:

Scrubbers
Fuel switching
Coal-fired boilers
Sulfur dioxide emissions
Dynamic discrete choice

ABSTRACT

The Acid Rain Program (ARP) was implemented in 1995. Since then, coal-fired boilers have had to choose among three main compliance alternatives: purchase pollution permits; switch to an alternative lower-sulfur coal; or adopt a scrubber. This decision problem is driven by the evolution of several economic variables and is revised when significant changes (to prices, quality of inputs, output level, technology, transport costs, regulations, among others) occur. Using a structural dynamic discrete choice model, I recover cost parameters and use them to evaluate two different counterfactual policies. The results confirm there is a trade-off between fuel switching and scrubbing costs (with the latter having a higher investment cost and a lower variable cost), and also the existence of regional heterogeneity. Finally, the ARP implied cost savings of approximately \$4.7 billions if compared to a uniform emission rate standard and \$14.8 billions if compared to compulsory scrubbing for the 1995–2005 period.

1. Introduction

Technology adoption and other reactions to environmental regulations are good examples of how important dynamic considerations are in many decision settings. In this study I estimate a dynamic discrete choice model where coal-fired electricity generating units (EGUs) decide among three main alternatives in order to comply with a major environmental regulation. The underlying justification for using such a model is that EGUs do not simply choose whether or not to retrofit the boiler, or to adopt a scrubber, or even purchase additional pollution permits, but also when to do so. An important result of this paper is that, after accounting for this feature of firm behavior, the data fit better with a model of forward-looking rationality than with simpler expectation specifications, such as myopic behavior or adaptive expectations.

An intended purpose of this paper is to support the inclusion of dynamic discrete choice methods in the fields of applied environmental and energy economics. The empirical application is itself relevant since many governments around the world are discussing how to implement environmental policies to combat global climate change, and in particular they are targeting the electricity generation sector.

Why should we look at electric power plants? The main causes of air quality deterioration are the air pollutants generated from burning fossil fuels in industrial facilities and electric power plants. The set of pollutants include: sulfur dioxides (SO₂), nitrogen oxides (NO_x), carbon oxides (CO and CO₂), particulate matters (PM), and toxics like mercury and radio-active materials.² In particular, SO₂ is a precursor of the Acid Rain, a well-known threat that affects human health, waters, forests and crops, in both dry and wet depositions.

Title IV of the Clean Air Act Amendments (CAAA) of 1990 (commonly referred to as the Acid Rain Program, ARP) created a two-phase scheme for SO₂ emissions reduction and marked a moving-away from command-and-control air quality regulations toward a market-based scheme. Under the ARP, fossil-fuel power plants were assigned allowances (i.e. pollution permits) on an annual basis and were free to select a cost-effective method to keep annual emissions under control. Besides fuel substitution and installation of pollution abatement technologies, a utility may shift allowances among its various EGUs or trade them with other utilities. Therefore, the cap-and-trade scheme introduced by the ARP allows an EGU with relatively high marginal abatement cost to complement its own emissions reduction with the purchasing of allowances from EGUs with lower

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¹ I would like to thank Jean Francois Houde, Alan Sorensen, Hector Nuñez, Michael Margolis, Alfonso Miranda, Hernán Bejarano, and seminar participants at University of Wisconsin-Madison and at CIDE and two anonymous referees for their very helpful comments and suggestions. All remaining errors are my own.

² See for example Goldstein and Izeman (1990).

marginal costs.³ Overall, a significant global reduction in SO₂ emissions has been reported for most states since the implementation of the program in 1995.⁴

Every period, an EGU has to make two important decisions. First, it has to choose how to comply with the environmental regulation. Clearly, that decision has dynamic implications and affects the long-run outcomes. It is revised whenever significant changes in the industry occur. For instance, major changes to total number of allowances allocated in the electric sector, availability of new coalmines located nearby, the construction of railroads that facilitate coal transportation, are all episodes that very likely impact on delivered coal costs and allowance prices. Consequently, several factors come into play when making this medium/long-run compliance decision. This idea is captured with a three-choice decision problem: adopt a capital-intensive pollution abatement technology, switch to a different fuel type, or simply trade emission permits.

Second, every period an EGU has to decide the electricity quantity to be generated. That is a short-run decision. Depending on the context, and specifically on whether the EGU operates in a deregulated or regulated market, it might enjoy different degrees of freedom in terms of the quantity of electricity to be generated. In this paper, I only focus on the first decision problem mentioned before (i.e., the discrete environmental compliance choice), and assume that every period output level is exogenously assigned to each EGU. More concretely, the quantity produced is drawn from the EGU-specific output distribution. As a result, the coal-fired generating unit forms correct expectations based on its empirical distribution of output. Clearly, this is a simplifying assumption that facilitates the dynamic model estimation. However, it is not completely arbitrary based on the observed facts.

1.1. Related literature

The Acid Rain Program implemented in the US (ARP) and the European Union Emission Trading System (EU ETS) are by far the most extensive applications of market-based approaches to pollution control. In particular, the ARP has largely been studied and several previous works have examined the incentives created by the program looking at its pros and cons.⁵ To the best of my knowledge, this is the first study to estimate a *structural dynamic discrete choice model* that contemplates the most relevant compliance strategies: i) burn high-sulfur coal and buy additional permits to cover excess emissions, ii) retrofit the boiler in order to burn low-sulfur coal, or iii) adopt a scrubber.⁶

Previous studies typically estimate reduced form regressions where policy implications critically depend on endogenously determined parameters. Predictions based on erroneously specified static models are biased because compliance cost estimates are biased. If, for example, the allowance price follows a particular dynamic path such that it decreases (on average) every period, then assuming EGUs anticipate this decreasing trend, both scrubbing and fuel switching become relatively more expensive over time. Therefore, if one erroneously assumes a static model, the corresponding estimates of scrubber adoption and fuel switching costs are biased. A similar analysis can be performed for the rest of observed state variables

³ According to Jostkow et al. (1998) the ARP is effective since it rests on a well organized mechanism that measures and records pollution emissions (the Allowance Tracking System maintained by the EPA) and because it imposes severe penalties on power utilities when their emissions exceed the number of allowances redeemed. In a recent work, Dardati (2011) evaluates the pros and cons of cap-and-trade systems comparing the ARP implemented in U.S. with the European EU-ETS system.

⁴ See for example Butler et al. (2001).

⁵ See the review by (Schmalensee and Stavins, 2013) or the study by Ellerman et al. (2000) for an evaluation of the first three years of ARP implementation in terms of emission reduction, compliance cost evolution, and the allowance market performance.

⁶ A scrubber is a capital-intensive pollution abatement technology capable of reducing SO₂ emissions up to 98%.

introduced later in the empirical model (i.e., coal prices, P^l and P^h , and EGU's capacity factor, CF). Determining the sign and magnitude of the biases caused by assuming an incorrect specification is a valuable empirical exercise. A troublesome assumption in static models is that agents' choices are not periodically revised. At the most, choices are revised when new regulations are passed (or implemented) without taking into account the different market conditions that arise with higher frequency (and not necessary at the time regulations are enacted). Changing market conditions are sometimes quite unpredictable and volatile in nature and clearly affect agents' expectations. In this context, a clear advantage of a dynamic model is that it incorporates expectations in a more precise and realistic manner. In the context of the ARP, scrubbing and fuel switching are indisputably dynamic choices that go beyond the decision of whether or not to do something. "When" is also relevant.

Some of the previous literature includes Carlson et al. (2000) which estimates the marginal abatement cost functions of power plants and evaluate the performance of the SO₂ allowance market; Ellerman et al. (1997) which calculates the average compliance costs for coal switching and scrubbing in 1995; Swinton (2002) which computes the shadow price of emissions reduction for plants located in Florida; Keohane, (2002, 2006a) and Keohane (2006b) which propose and estimate a model of scrubber adoption and fuel switching costs. Other papers study the technology diffusion mechanism associated to scrubber adoption. For instance, Frey (2013) estimates a duration model to compare the effects of different regulation schemes in the power generation industry. Although her estimation procedure is able to identify different variables that stimulated (or discouraged) scrubber adoption, it is not helpful to compute the relative costs of different environmental compliance alternatives or to answer hypothetical questions or counterfactuals. Bellas (1998) analyzes the cost of scrubbing at coal-fired power plants trying to find evidence of technological change over time. The author studies boilers regulated under the New Source Performance Standards (NSPS) of the 1970 and 1977 Clean Air Acts Amendments, failing to find any effects of scrubber vintage on costs.

The contribution of this study is twofold. First, it fills the gap in the existing literature with a structural model that provides estimates of relative cost parameters associated to each compliance strategy. The dynamic nature of my model incorporates expectations in a realistic fashion and the corresponding parameters are reliably estimated. Second, I use the estimates to evaluate the cost savings achieved through the implementation of the ARP. In the comparison, I use the following *command-and-control* counterfactual policies: (a) a uniform emission rate standard of 1.2 pounds of SO₂ per million Btu; (b) forced scrubber adoption. These two policies resembles, to some extent, the schemes imposed by the Clean Air Act Amendments of 1970 and 1977, respectively. Given the magnitude of the ARP, a precise estimation of its impact on power generation costs is extremely important. The methodology used in this paper to estimate the structural dynamic model is based on a full solution method that solves the full dynamic programming problem. Concretely, I use a nested fixed point algorithm as suggested by Rust (1987). An alternative to a full solution method would be to employ a simulation/approximation-based approach such as the ones proposed by Hotz and Miller (1993) or Aguirregabiria and Mira (2002), at the expense of accepting lower efficiency of the structural parameter estimates.⁷

The rest of the paper is organized as follows. Section 2 briefly describes the ARP and the context where coal-fired boilers operated. Section 3 presents a formal model where boilers have to decide among

⁷ A rich description and discussion of different estimation approaches to discrete choice dynamic programming models (with several examples of empirical applications) can be found in Eckstein and Wolpin (1989), Rust (1994, 1996), Ericson and Pakes (1995), Miller (1997), Keane and Wolpin (2009), Arcidiacono and Miller (2011), Aguirregabiria and Mira (2010), among other survey papers.

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