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Incorporating oligopoly, CO_2 emissions trading and green certificates into a power generation expansion model☆

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Abstract

This paper presents a generation expansion model for the power sector which incorporates several features that make it very interesting for application to current electricity markets: it considers the possible oligopolistic behavior of firms, and incorporates relevant policy instruments, carbon emissions trading and tradable green certificates. It combines powerful traditional tools related to the detailed system operation with techniques for modeling the economic market equilibrium and a formulation for the resolution of the emissions permit and tradable green certificates market equilibrium. The model is formulated as a Linear Complementarity Problem (LCP) which allows the optimization problem for each firm considering the power, carbon and green certificate markets to be solved simultaneously. The model has been implemented in GAMS. An application to the Spanish power system is also presented.

Keywords: Generation-expansion modeling; Carbon emissions trading; Green certificates; Oligopoly

1. Introduction

The electricity industry around the world has been experiencing significant changes at an unprecedented pace in its history. Electricity markets worldwide are being deregulated on the generation and retail sides, and this is bringing about two major changes: on the one hand, there is an almost total freedom when deciding on the expansion of generation facilities. On the other hand, firms are subject to competition (which in most cases is imperfect) in the generation market.

In this new context, electricity generating firms are subject to much more significant challenges when making decisions. Also regulators face a more difficult task of monitoring the present and future evolution of the power sector. Therefore, both types of agent require new models and adequate tools to cover these new functions, since in most cases, traditional approaches become much less useful (Dyner & Larsen, 2001).

In addition, besides these changes in the organization of the industry, growing concerns about environmental issues have led to the establishment of several energy and environmental policies, of which the most relevant are those derived from the Kyoto Protocol for the reduction of greenhouse gas emissions as well as those promoting renewable energies. These policies have also to be adequately considered by electric utilities for their decision making, and regulators for their monitoring, since they may have a significant impact on the profitability of investments and on the economic and environmental performance of the power sector.

Currently, one of the major Kyoto Protocol consequences is the establishment of a carbon emissions trading scheme. Although the global market has barely started, the European Commission has introduced a Directive for an internal Emissions Trading Scheme (ETS) which started in 2005 (European Commission, 2003) and is already producing some trade. Although most models are just using exogenous carbon prices, the electricity sector is a major player in this market, and may therefore affect prices significantly with its behavior. Therefore, it seems appropriate to model together both the power and carbon markets and thus obtain endogenous prices from both.

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Regarding renewable energy promotion policies, the two options mostly used are: price systems (premiums) and quota systems (usually associated with tradable green certificates). Although the first are more widespread, due to their seemingly better performance (Menanteau, Finon, & Lamy, 2003), their modeling as an exogenous premium for deciding on generation expansion is somewhat short-sighted. Indeed, premiums are not static, but rather based on implicit quota objectives set by regulators. Therefore, we consider that they should be modeled as quota systems, since that allows for an endogenous generation of the premium.

Combinations of both policies already exist in some power markets: the UK and Italy feature both tradable green certificate systems and the carbon trading system imposed by the European ETS. If we consider, as mentioned before, that feed-in tariffs may also be modeled as implicit quotas, then most of European countries are already experiencing the impact of both policies.

In this paper, a generation-expansion model for the power sector is presented which incorporates all the above-mentioned aspects, so that it may respond adequately to the needs of firms and regulators in the current electricity markets: it considers the possible oligopolistic behavior of generating firms, and also introduces into the model carbon emissions and tradable green certificates markets. The paper is structured as follows: Section 2 presents the state of the art of generation-expansion models, while Section 3 describes in detail the model presented. Section 4 shows an application of the model to a real case, the Spanish electricity sector. Finally, Section 5 provides the conclusions drawn from the study.

2. State of the art

There are not many references in the literature of generation-expansion models for power systems which adequately address the challenges expressed above: simulation of oligopolistic behavior and modeling of carbon emissions and green certificate markets. This may be due to the change in the conditions of power markets (basically, their deregulation and liberalization) which have made obsolete most of the previously existing models, as correctly pointed out by Dyner and Larsen (2001). However, there have been several partial approaches.

Regarding the simulation of oligopolistic power markets, a lot of research has been carried out lately, of which an extensive review is given in Ventosa, Baillo, Ramos, and Rivier (2005). In many of these models, generating companies are assumed to behave as Cournot players (see e.g. Rivier, Ventosa, and Ramos (2001)). However, a number of drawbacks seem to question the applicability of the Cournot model. The most important one stems from the fact that under the Cournot approach, generators' strategies are expressed in terms of quantities and not in terms of supply curves. Hence, equilibrium prices are determined only by the demand function, therefore are highly sensitive to demand representation and usually higher than those observed in reality. This limitation may be overcome by introducing the Conjectural Variations approach described in traditional microeconomics theory (Vives, 1999). The CV approach is easy to introduce into Cournot-based models (Day, Hobbs, & Pang, 2002; García-Alcalde, Ventosa, Rivier, Ramos, & Relaño, 2002) since resulting models can be stated as a Linear Complementarity Problem (LCP) (for an overview of LCP see e.g. Cottle, Pang, and Stone (1992)).

As for the modeling of carbon emissions markets, this has generally been done only in larger scale, energy-economy-environment models, of which a very thorough review is presented, for example, in Huntington and Weyant (2004). However, these models have little detail for the electricity sector (which, as mentioned before, is a relevant player in carbon markets). Some studies in which the electricity sector is modeled together with emissions markets (for SO_2 and NO_x, not for carbon) were those developed in the US under the Clean Air Act (see e.g. Hobbs (1993)). The GETS initiative carried out by Eurelectric (2004) tried to represent carbon emissions markets within the European electricity sector. Also for Europe, Hindsberger, Nybroe, Ravn, and Schmidt (2003), Jensen and Skytte (2003) and Morthorst (2001), or Unger and Ahlgren (2006) have looked at the specific impact of carbon trading on the Nordic countries electricity sector. In particular, these studies also model tradable green certificate schemes, so that they are the closest attempt we know at answering the modeling challenges mentioned before. The problems with these models are that they only look at the electricity sector and not the other sectors which might participate in a carbon emissions trading scheme, and that they are not able to represent adequately electricity sectors under imperfect competition.

Imperfect competition in the power sector and tradable emission allowances are addressed by Chen and Hobbs (2005), although they look at NO_x, not CO_2. We may also cite two studies which model an oligopolistic market under emissions trading regimes, Nagurney, Dhanda, and Stranlund (1997) and Nagurney and Dhanda (2000). However, the latter are too general and unable to cope with the technical specificities of the electricity sector. Neither of them model the promotion of renewable energies.

Finally, the authors of the present paper developed lately an oligopolistic, generation expansion model with carbon emissions trading (Linares, Santos, & Ventosa, 2006a,b). However, this model did not consider the green certificate market and therefore the interesting interactions which result from these two policy measures (see e.g. Jensen and Skytte (2003)).

Therefore, as can be seen, there is a current need for generation-expansion models able to represent adequately carbon emissions and tradable green certificate markets in a power sector under imperfect competition. The GEPAC model, which tries to address all these issues, is presented below. This paper also presents a detailed mathematical description of the model, an element missing in previous work.

3. The GEPAC model

3.1. Model overview

The electricity market is modeled as one in which, in the short term, firms compete in quantity of output as in