Applied Energy 96 (2012) 203–211

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Market power in emissions trading: Strategically manipulating permit price through fringe firms

Makoto Tanaka [a], Yihsu Chen [b,*]

[a] National Graduate Institute for Policy Studies (GRIPS), 7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan
[b] School of Social Sciences, Humanities and Arts, School of Engineering, University of California – Merced., 5200 N. Lake Rd., Merced, CA, USA

ARTICLE INFO

Article history:
Received 14 June 2011
Received in revised form 4 August 2011
Accepted 30 August 2011
Available online 20 October 2011

Keywords:
Cap-and-trade
Electricity
Market power
Cournot-fringe

ABSTRACT

Tradable emission permits have received considerable attention recently. One emerging issue is its interaction with electricity markets, specifically, market power in the permit markets. One challenge in studying market power in the permit markets is that the demand for permits is implicitly determined by the system conditions. Traditional ways of modeling market power (e.g., standard Cournot model) cannot directly apply. This paper develops a model in which Cournot firms in the market can manipulate the permit price through fringe firms. We have two central findings in this paper. First, diverting emission permits from Cournot to fringe producers always reduce the power and the permit prices, which could improve social surplus. Second, when the fringe producer's emission rate is low, diverting permits from the "dirty" (i.e., more-polluting) Cournot producer to the "clean" (i.e., less-polluting) Cournot producer leads to a decline of both power and permit prices. Therefore, the initial allocation of the emission permits could be a useful regulatory tool to mitigate the abuse of market power. We also illustrate these results through a numerical simulation of the California electricity market.

1. Introduction

Considerable attention has been paid to the cap-and-trade (C&T) programs recently as C&T becomes a common tool used by authorities to regulate greenhouse gas (GHG) emissions from the electricity sector. Examples include the European Union Emission Trading Scheme (EU ETS), Regional Greenhouse gas Initiative (RGGI) in Northeast United States as well as California program under AB32, which is expected to become effective in 2012.[1] There are also growing concerns over which tradable pollution permits under these C&T programs could be used by firms to manipulate the competitive electricity market in their favor by driving up permit prices [1]. Empirical analysis of the 2000–2001 power crisis in California suggests that a large generator put a cost-squeeze on other firms by intentionally consuming more permits than necessary, raising permit costs for other companies that were short of permits [2]. Permit shortages and high permit prices were reasons offered by some generators for their inability or unwillingness to generate power in the warming months of 2000.

The issues of market power in the electricity market have been subject to a great body of research for obvious reasons. The consequences of market power can include price distortions, production inefficiencies, and a redistribution of economic rents among entities in the market. Many models have been developed to analyze market power in electricity markets (see reviews in [3–5]). These models are applied to assessing the impact of various changes in institutional settings or market conditions: market design (e.g., bidding rules, type of transmission rights or geographic scope of permits markets), market structure (e.g., ownership, amount of transmission capacity) upon electricity prices and market efficiency. The solution of these models is usually based on the Nash equilibrium concept. Nash equilibrium of markets can be found for several different types of strategies (e.g., quantity strategies for a Cournot–Nash game, price strategies for a Bertrand–Nash game, supply-function equilibrium, or collusive strategy in a supergame structure). Then various comparisons can be made to its counterpart based upon a pure competition scenario, or Nash prices under different market scenarios. Among various types of strategies, a quantity-based Cournot formulation is most commonly used for at least two reasons. First, the mathematical tractability and the flexibility to incorporate rich details can provide insights on prospective market, technology, and policy designs before the changes were implemented in the markets. Second, empirical studies have also shown that the Nash–Cournot outcomes serve a good approximation to the actual market conditions [6].

* Corresponding author. Tel.: +1 209 228 4102; fax: +1 209 228 4047.
E-mail addresses: mtanaka@grips.ac.jp (M. Tanaka), yihsu.chen@ucmerced.edu (Y. Chen).

[1] See, for example, Zhang and Wei [7] for an overview of current research on EU ETS. Tolis and Rentizelas [8], and Tsai and Yen [9], among others, discuss the issue of CO_2 emissions trading in the context of power sectors.

0306-2619/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2011.08.049

One of the prerequisites of formulating producers' strategies based upon the Cournot concept is the knowledge about inverse demand function of the underlying commodities. This assumption appears to be reasonable when it comes to modeling the electricity markets. This is in part because producers repetitively engage in market transactions such that they have opportunities to learn from market outcomes after the markets are settled. However, the demand function of pollution permits, on the other hand, is not easy to come by. One approach that has been proposed to study the consequences of exercising market power in the emission permits market is by formulating the producers' problem using a conjectural variation approach [1]. Conjectural variation is typically viewed as a reduced-form approximation to the repeated dynamic games.[2] A conjectural variation approach generalizes the Cournot models by more flexibly allowing the conjecture parameters to be varied by different producers, or be a function of capacity ownership or a producer's net position in permits market. One of the premises of the conjectural variations is that players learn from their experience. However, such premise might be difficult to satisfy with when modeling strategic behavior in the emission trading markets. One obvious reason is that in a typical emission trading program, facilities are only required to show their compliance on a quarterly or annually basis. Producers are also allowed to bank or borrow emission permits in some programs. The chances that they can learn from market transactions are significantly reduced, and therefore the conjecture variation parameters used in the models might not be credible.

If one single producer dominates the markets, a natural way to study the consequences of market power is to formulate the problem as a leader–follower or the Stackelberg game. In a sense, the conjecture parameters derived under the Stackelberg approach coincide with the followers' actual best responses. For example, Chen et al. [11] studied the ability of the largest producer in the electricity market to manipulate both the electricity and emission markets by formulating the problem as a leader–follower game.[3] The paper found that the leader can gain substantially by withholding emission permits to effectively driving up the permits price. However, given the strong oversight by the regulator agency, the chances that a single producer can dominate the markets could be very small. This suggests that a oligopoly market is more likely to prevail in the reality.

Issues related to market power in the permit market or transferable pollution property rights have been of great interest. Hahn [12] is the first to theoretically study the market power problem in a tradable permit system by using a ''dominant firm-competitive fringe'' model. In his paper, firms minimize the pollution abatement costs subject to a C&T program with some initial permits. He concluded that the efficiency loss of permit programs is in proportion to the degree of deviation of initial allocation from its competitive level. Misiolek and Elder [13] extended Hahn's market structure to the product market, and investigate the interaction with the permit market. They showed that a single dominant firm can manipulate the permit market to drive up the fringe firm's cost in the product market. Variants of these models have been developed with more realistic assumptions to address similar questions (see for example [14–16]).

Modeling market power in permit markets using a ''Cournot firms-competitive fringe'' structure was first analyzed by Westskog [17]. She constructed a model in which some countries are Cournot players while others are price-takers. However, her model assumed market power in the permit market, without explicitly considering the product market. von der Fehr [18] and Sartzetakis [19] pursued other directions by studying two-stage Cournot models for emissions permit trading, but without competitive fringes. More recently, Tanaka [20] examined a multi-sector model of tradable emission permits, which includes Cournot and perfectly competitive industries. He showed how the distribution of permits to the asymmetric Cournot firms not only affects oligopoly industries but also perfectly competitive industries (different products) through the tradable permit markets. However, to the best of our knowledge, ''Cournot firms-competitive fringe'' models in the context of emissions permit trading have not been fully investigated in the literature.

This paper develops a general model in which Cournot firms can manipulate the permit and electricity price in their favor through fringe firms. Therefore we extend the previous work by considering the market outcomes in both product, i.e., electricity, and pollution permit markets. In particular, the first-order condition associated with the fringe's problem is explicitly included as the Cournot firms' constraints. Cournot producers would then strategically determine output quantities and the permit prices to maximize their profits. The equilibrium is determined by equating the permit prices among Cournot producers. Furthermore, in order to derive intuitive theoretical results, we limit our attention to a Cournot duopoly with fringes, and focus on the effect of initial permits distribution on the market equilibrium. We then apply the model to simulate the California electricity market. The analytical model is used to generate contestable hypotheses, while the numerical simulation gives more meaningful and intuitive interpretation of the results.

We have following findings in this paper. Diverting emission permits from Cournot to fringe producers always reduce the power and the permit prices, resulting in an increase in social surplus. On the other hand, the effect of redistribution of permits among Cournot producers on the power and permit prices could go either way, depending on the emission rate of the fringe producer. When the fringe producer's emission rate is low, diverting permits from the ''dirty'' (i.e., more-polluting) Cournot producer to the ''clean'' (i.e., less-polluting) Cournot producer leads to a decline of both power and permit prices. The reverse is true when the fringe producer is relatively dirty. We also show that there exists a threshold emission rate associated with the fringe producer that separates those two cases. The simulation of the California electricity market with Cournot and fringe firms illustrates that Cournot firms can significantly raise both power price and CO_2 permit price, which results in a great loss in social surplus. Moreover, the numerical results are consistent with the theoretical conclusions regarding the initial permits allocation.

The paper is organized as follows: In Section 2, we present a Cournot-fringe model with both product and permit markets. Section 3 provides a qualitative analysis on the effects of changing the initial permit allocation. After discussing the basic setting of our numerical model in Section 4, we apply our theoretical model to the California electricity market in Section 5. Section 6 contains the concluding comments.

[2] The conjectural variation model generalizes the Cournot model by assuming that each firm believes that marginal revenue can be expressed by $MR = P + \frac{dP}{dQ}\frac{d(q_f + q_{-f})}{dq_f} q_f = P + \frac{dP}{dQ}(1+\theta)q_f$. Some particular cases include Bertrand/perfect competition ($\theta = -1$), Cournot competition ($\theta = 0$), and perfect collusion ($\theta = N - 1$). As pointed out by Tirole [10], although it is appealing to model dynamic features using a static framework based upon conjectural variations approach, any conjecture that deviates from no reaction in a static game is irrational since no information is available. However, such approach could be useful to empirically estimate the degree of market and competitiveness. Examples include Puller [21], Bushnell et al. [6] and Mansur [22].

[3] The resulting mathematical problem is a Mathematical Program with Equilibrium Constraints or (MPEC) [23]. The difficulty of this type of problems is that the constraint qualification (CQ) is not satisfied, and global optimality is not guaranteed. When multiple leaders exist, the resulting problem with which each individual's problem is modeled by a MPEC is referred to as an Equilibrium Problem with Equilibrium Constraints (EPEC). Solving an EPEC has proved to be also challenging. Several papers have attempted to solve EPECs, see for example Su [24], Hu and Ralph [25] and Yao et al. [26].