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The strategic robustness of oligopoly electricity market models ☆

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ABSTRACT

Modeling market power in electricity markets is fraught as agents compete in prices but interact daily. In deciding what supply to offer, generators need to form judgements on the supplies chosen by rivals and hence the residual demand they face. Many markets are found to have prices above competitive levels, which could be explained by Nash-Cournot behaviour or marking-up above variable costs, but these strategies may not be robust against sophisticated deviants. This paper demonstrates that (1) the Nash choice of the optimal proportional mark-up on marginal costs yields lower prices and profits than Cournot behaviour but higher prices and profits than the optimum fixed mark-up; (2) such mark-up models are robust to single firm Nash deviations, but not against more sophisticated deviations in the deterministic case, nor under demand uncertainty. Proportional mark-up models emerge as the most robust and hence preferred modeling approach.

1. Introduction

Most liberalized electricity markets suffer from market power, with high concentration indices, and are frequently subject to market investigations (see for example DG COMP, 2007). Academics and consultants alike struggle to model the exercise of this market power and the implications of possible reforms, such as increasing interconnection (Newbery et al., 2004), moving to nodal pricing (Joskow and Tirole, 2000), market coupling (Newbery et al., 2016), breaking up larger companies such as EdF in France (INSEAD, 2004), introducing capacity auctions (Entriken and Wan, 2003; Genoese et al., 2012; Hach et al., 2015; Hu and Hobbs, 2008) or by increasing the volumes of renewables (Liski and Vehviläinen, 2015; Newbery, 2016). The main problem facing those wishing quantified results rather than illustrative examples lies in the considerable difficulty of modeling strategic behaviour in markets with various capacity and transmission constraints, in which the participants interact daily on auction markets under conditions of great transparency.

Electricity is possibly the best example of the textbook example of a perfectly homogenous product that would seem to favour intense price competition, but, as observed above, liberalized electricity markets are characterized by oligopoly and deviations from competitive behaviour. Moreover, generators have very complete information about their own and rivals' short-run cost functions, which are determined by known technologies and observable fuel prices. Cournot models may be suitable for modeling potential market power and prices for specific levels of demand (Moselle et al., 2006) but electricity demand varies substantially hourly, daily and seasonally. In practice, and more extensively now that the EU has almost completed market coupling at the day-ahead stage,

☆ This was written as a Research Fellow at the Department of Electrical and Electronic Engineering, Imperial College London; contact address: Faculty of Economics, Sidgwick Avenue, Cambridge UK CB3 9DE; email: dmgn@cam.ac.uk. This is an extension of Newbery (2012), correcting the labelled Stackelberg equilibria to Nash equilibria and clarifying what is meant by Stackelberg behaviour. We are indebted to Rich Gilbert, Robert Ritz and Marta Rocha for comments, and to a number of helpful referees, but remaining errors are ours alone.

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generating companies offer their supply as a function of offer prices (often a step function, see Newbery et al., 2013) into EUPHEMIA,[2] the auction platform that determines day-ahead prices for the whole of the market-coupled EU. The natural way of modeling the outcomes of that auction are to look for Supply Function Equilibria, but these are notoriously hard to solve or even simulate (Day et al., 2002).

Nevertheless, the central idea of a supply function is helpful, in that it requires agents to form a view of the supplies offered by other generators, which, when subtracted from total demand, gives a perceived residual demand. Each agent can then choose an optimal supply response. If all agents have well-defined supply behaviour it is in principle possible to find a Nash equilibrium in which each oligopolist maximizes its profits given the behaviour of other market participants. The agents may choose to offer fixed quantities – Cournot behaviour – or may choose to mark-up their offers on their variable costs, and the relevant demand facing those with market power may have competitive supplies subtracted from total demand.

The central point of this paper is that while the residual demand facing an agent depends on the choices of other agents, the assumption that the market will settle at the Nash equilibrium of these specific choices needs to be tested for robustness. The equilibrium will not be robust if it is profitable for an agent, knowing the strategies of all other players, to choose a different strategy.

This paper tests the robustness of various popular modeling approaches for an electricity market with a small number of players. We study two particular forms of mark-up pricing: fixed and proportional, where in the former, firms set a fixed mark-up on their marginal cost schedule and in the latter, firms choose a proportional mark-up. We analyze these two mark-up pricing models because most studies (some of which are reviewed below) find that where electricity markets are concentrated, generators are selling at prices above the competitive short-run marginal cost. They have the attraction that the choice of a single parameter (the mark-up) considerably simplifies the modeling problem (Weidlich and Veit, 2008). More important, they are consistent with the forms of offers that are allowed in most power exchanges and by EUPHEMIA. We compare the results with the standard Nash-Cournot model in which agents just choose the quantity to supply to the market. In auction markets like power pools and EUPHEMIA this would require producers to offer a fixed amount at some minimum price (e.g. variable cost) and then receive the price set by the interaction of total supply and demand.

We note that for the case of linear marginal costs and linear demand, the supply function equilibrium is a proportional mark-up model (Klemperer and Meyer, 1986), but we are interested in a wider set of cost and demand functions. One of the main conclusions of this paper is that the proportional mark-up model would seem to have wider appeal in modeling market power than just in the linear case, and in that sense it forms a useful simplification of complex supply function models that lends itself to modeling market power.

We examine the robustness of both forms of mark-up pricing and ask whether these models are robust against more sophisticated (Stackelberg) strategies. If so, they pass the first test of plausibility, but if not, then modelers need to be aware of their fragility and consider alternatives, which we discuss. Throughout we assume a market structure similar to electricity pools (e.g. Green and Newbery, 1992) or the EUPHEMIA European platform, which is a last-price auction in which offers from generators and bids from suppliers are submitted and the market clearing price is determined (subject to various constraints, such as transmission capacities). We assume that the daily interaction on the auction market or power exchange, combined with cost transparency, makes it plausible that agents know or learn the supply behaviour of their rivals. They are also assumed to know how the market clearing price is set, bearing in mind that different plants have different costs (different efficiencies, different fuels) and demand varies hourly, by day of the week, and seasonally.

We show that the two mark-up strategies considered are more competitive than Nash-Cournot behaviour, with the Nash choice of the optimal proportional mark-up on marginal costs yielding lower prices and profits than the Cournot oligopoly but higher prices and profits than the optimum fixed mark-up on marginal costs. In deterministic cases, the mark-up equilibria are robust against Nash deviations by single firms choosing quantities (or any other actions) instead of mark-ups. However, these mark-up equilibria are not robust to more sophisticated single-firm Stackelberg deviations in which the deviant maintains her output and the remaining players adapt to that and find the corresponding mark-up equilibrium output levels. This would be achieved by the deviant repeatedly offering the same supply into an auction market (like a pool or the EUPHEMIA platform) and the remaining players then groping towards their most profitable response. The deviant player makes higher profits following this Stackelberg strategy. If demand is stochastic, then a fixed quantity response (deterministic Cournot) is strictly inferior to either mark-up equilibria. In the case of linear marginal costs and linear demand, the proportional mark-up equilibrium as a supply function equilibrium is robust against any deviation, while a fixed mark-up is vulnerable to a proportional mark-up deviant.

This paper makes a number of contributions to the literature on electricity market modeling and oligopoly pricing. It first sets the scene by ranking in order of profitability three common market equilibrium models: the standard Cournot model (in which producers offer a fixed quantity into the auction platform and the price is set by the demand side),[3] and two price-setting models in which firms set prices as mark-ups on their marginal costs. This allows us to test their robustness against various kinds of deviations by single and multiple firms, first on the assumption of certainty, and then under uncertainty about demand levels. If, as in most industrial commodity industries and particularly for electricity, marginal costs are increasing, we find that proportional mark-ups emerge as the more attractive pricing model, which we relate to the literature on supply functions usually connected to electricity markets. These findings are relevant to the considerable literature on simulation modeling of such industries, widely used in investment analysis, policy reform (e.g. Green and Newbery, 1992, commenting on restructuring state-owned monopoly generation companies) and anti-trust investigations.

The paper is organized as follows. In Section 2, we briefly survey different modeling approaches to oligopolistic electricity markets. In Section 3, we introduce our mark-up models and test their robustness to Cournot deviations. Section 4 tests our models against Stackelberg deviations. Section 5 concludes.

2. Modeling oligopolistic electricity markets

Electricity markets have the great advantage for the study of market power in that high resolution price data (hourly or half-hourly) are available, together with aggregate demand and supply in that period (and sometimes individual company's supply, e.g. Sweeting, 2007). Variable costs are also easy to simulate, and in some markets are observable for each generation company (e.g. in the Single Electricity Market of the island of Ireland). One standard test of market power is benchmark analysis using estimates of the short-run marginal cost of production (given by fuel prices and conversion efficiencies and aggregating across all marginal costs) to

[2] 1 Pan-European Hybrid Electricity Market Integration Algorithm: see https://www.apxgroup.com/wp-_content/uploads/Euphemia-_Public-_Documentation.pdf.

[3] Often rationalised in a world of certainty as a capacity-constrained short-run equilibrium in which agents set prices (Kreps and Scheinkman, 1983).