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The supply function equilibrium and its policy implications for wholesale electricity auctions

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A B S T R A C T

The supply function equilibrium provides a game-theoretic model of strategic bidding in oligopolistic wholesale electricity auctions. This paper presents an intuitive account of current understanding and shows how welfare losses depend on the number of firms in the market and their asymmetry. Previous results and general recommendations for divisible-good/multi-unit auctions provides guidance on the design of the auction format, setting the reservation price, the rationing rule, and restrictions on the offer curves in wholesale electricity auctions.

1. Introduction

The wave of restructurings in the electricity supply industry prompted by experience in Britain and Chile, and in Europe under pressure from a succession of EU Directives, raises new issues for regulators. The former vertically integrated industry needed regulation of the final prices (explicitly, if privately owned, or implicitly, if state owned). Restructuring aimed to create competing generating companies selling into a wholesale market, with competing retailers buying to supply their customers. As electricity cannot readily be stored, a system operator is required to take charge of balancing instantaneous demand and supply and ensuring that the current flowing through the transmission links does not exceed safe limits by calling on generators in different locations to adjust their output. Restructuring may result in too few generating companies located within constrained market areas (which are unable to import alternative generation from outside the zone because of transmission constraints), raising issues of market power. Finally, demand and supply vary considerably over the course of a day and season, and both are subject to sudden shocks, caused by plant or line failures, weather changes and even the half-time break in a major sporting event.

As a result the wholesale market and the balancing market or mechanism need careful design to ensure efficient dispatch at acceptable prices. This paper addresses the question of what we have learned from the analysis of such markets, an active topic in the economics of Industrial Organization and auction theory, as the traditional models of imperfect competition have proven unsatisfactory for these very specific features of electricity markets. In contrast to most other markets, the way price is determined is very well defined in the standard model of a wholesale electricity market. Each producer submits an offer curve that specifies how much it is willing to produce at different prices. Similarly, consumers and retailers (suppliers), who represent small consumers, submit demand (or bid) curves specifying how much electricity they want to buy at different prices. The design of the market can influence price formation and how competitive the market will be by choice of the auction format, the level of any price cap, the rationing rule, and by making restrictions on the offer curves. When making their choice regulators should consider the impact on participants' contracting and investment incentives under various market designs and rules.

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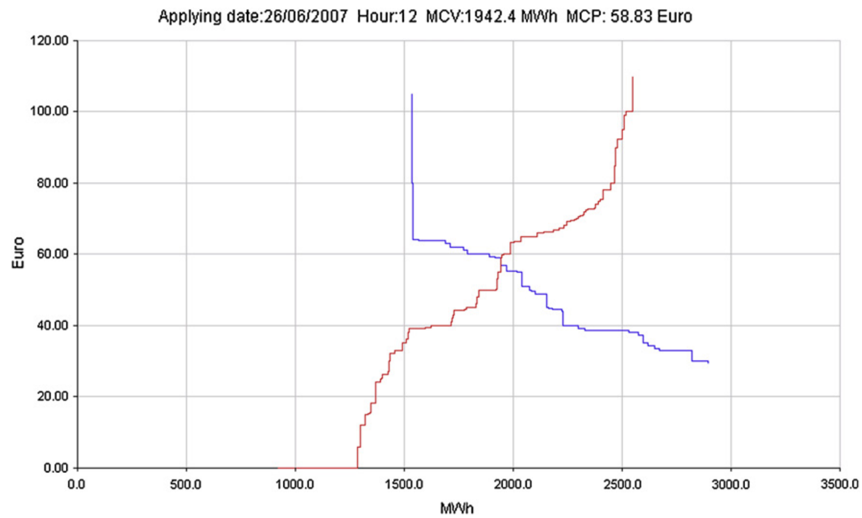

Fig. 1. Market clearing price detail from APX Hour 12, 26 June 2007.

Competition authorities also need to predict electricity prices under various counterfactuals – what might happen if a merger or acquisition is accepted or an interconnector built? Often authorities are content with using concentration measures, such as the Herfindahl–Hirschman index (HHI), to assess the degree of competition in the market. However, these measures work poorly for electricity markets, where demand and supply must be instantly balanced and where the tightness of reserve margins and transmission capacity constraints can vary considerably over short periods with significant impacts on prices (Borenstein et al., 1999; Ofgem, 2000). Thus given installed production capacities, it depends very much on the level and location of instantaneous demand whether the market will suffer from the exercise of market power.

Fortunately, we have made considerable progress in developing a more suitable model – the supply function equilibrium – to address these questions. This paper qualitatively assesses the two leading auction formats, the uniform-price and pay-as-bid formats, and other rules of electricity auctions using supply function equilibria under uncertain demand. We provide new results highlighting how short-run welfare losses depend on the number of firms in the market and their asymmetry.

The paper is organized as follows. The remainder of this section sets out the structure of the electricity wholesale market to motivate the justification for the supply function equilibrium (SFE) model, Section 2 characterises the SFE and surveys the literature. Section 3 draws out the implications for the analysis of market power, derives expressions for the deadweight cost of that market power and the effect of forward contracting on both. The section concludes with a brief summary of the empirical support for the SFE model. Section 4 examines possible market design remedies and Section 5 concludes.

1.1. The wholesale electricity market

Electricity is produced by many different technologies that often have very different marginal costs. The production cost of a plant is primarily determined by fuel costs and its efficiency that are well-known and common knowledge. The plants of a producer are used in merit order, starting with the lowest marginal cost, such as nuclear power or hydro-power. Last in the merit order are peaking plants, such as open-cycle gas turbines burning natural gas or oil with high variable and low capital costs. The merit order implies that producers' marginal costs increase with output. There are some local deviations from this trend, as start-up costs introduce local non-convexities, but these are normally neglected in market analyses (though not in optimal scheduling programmes). Although electricity may be produced by various technologies, it is still a completely homogeneous good suitable for trading on commodity exchanges and auctions.

In wholesale electricity markets, producers sell electricity to retailers. In their turn, retailers sell electricity to consumers in the retail market. Electricity consumption is to a large extent determined exogenously, e.g. by the weather and work-days or holidays, and is very inelastic, especially close to the time of consumption.[3] This limited flexibility means that retailers' market power in the wholesale market is small compared with that of generators, which can be significant.

Due to restrictions on the rate that fossil generation can ramp-up output, particularly from a cold start, production plans are scheduled the day before delivery, and the day-ahead (or prompt or spot) market is an important component in this planning process. A well-designed liquid market can provide the strike prices for financial contracts. The day-ahead market is typically organized as a double auction to which retailers and producers submit non-increasing bid curves and non-decreasing offer curves, respectively, as shown in Fig. 1. The market clearing price (MCP in Fig. 1) is determined by the intersection of the bids and offers. There is normally a separate price and auction for each delivery period, typically a half-hour or hour but which can be as short as 5–15 min, even if, as in many markets, the generators' offer curves must be valid for the whole of the next day.

Electricity is special in that supply must equal consumption at every instant, because it is very expensive to store electrical energy on a large scale. The system operator uses a real-time or balancing market to make necessary adjustments to production (and consumption to the extent that it bids into the market) during the delivery period by accepting additional power production from, or by selling back electricity to, producers. Offers to the balancing market are submitted before the delivery period starts but demand is uncertain when offers are submitted. System imbalances arise

[3] Demand can bid usually into the market, but in Britain the amount in the past was small – 2000 MW compared to peak demand of over 50,000 MW. Smart metering may change this in future.