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The role of market pricing mechanism under imperfect competition

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Abstract

This paper illustrates how a supplier profit may be affected by the market pricing mechanism under imperfect competition. A parameterized Supply Function Equilibrium (SFE) model involving manipulation of the sole intercept is used to represent the strategic behavior of each supplier. Through utilizing a bilevel optimization technique and a Mathematical Program with Equilibrium Constraints (MPECs) approach, market equilibria are calculated and compared under pay-as-bid pricing (PABP) and marginal pricing (MP) mechanisms. For an unconstrained case, analytically it is demonstrated that the optimal bidding strategy and the maximum profit of each supplier, as well as the market clearing price are the same under PABP and MP. The effects of the transmission limits and the supplier capacity constraints are discussed through numerical results.

Keywords: Bidding strategy; Electricity market; Marginal pricing; Nash equilibrium; Pay-as-bid pricing; Risk profile

1. Introduction

The most common approaches for auctioning electricity markets are sealed-bid mechanisms. Suppliers offer supply schedules and supply curve which exhibits price versus cumulative quantity is formed. The intersection of the supply and demand curves determines the market clearing price. All bids submitted at a price lower than or equal to the market clearing price are accepted and paid according to either pay-as-bid pricing (PABP) or marginal pricing (MP) mechanism. Under PABP scheme, suppliers are paid their own bids that have offered to the independent system operator (ISO), whereas under MP scheme, accepted suppliers are paid the market marginal price (either the last accepted price-offer, or the first rejected price-offer). PABP mechanism may force suppliers to bid higher than their marginal costs in order to make profit while under MP suppliers gain profits even if they bid their marginal costs.

The choice between MP and PABP mechanisms for electricity markets and the arguments for and against them have been the subject of recent studies [17,20,9,30,16]. Although revenue equivalence result [17] suggests that the expected payment in a uniform pricing scheme will be identical with that in a PABP mechanism, some papers argue in favor of MP (see e.g., [30,16]) because of other considerations such as fairness and efficiency. MP is recognized efficient since bidders have an incentive to reveal their true costs and the resulting dispatch will be efficient [20]. MP is also known to be fair because all winners receive (or pay) the same price and nonwinners fail to win as they refuse to offer at or less than the market

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clearing price [9]. A potential problem with MP is that whenever a supplier can influence the price, MP mechanism gives the supplier an opportunity to exercise market power by bidding above its marginal cost. PABP is recommended as a way to prevent the exercise of market power. In contrast to MP, under PABP there is no incentive to increase the offer curve above marginal cost in an effort to increase the price received on all quantity offered below the market clearing price [9]. Reduced price volatility is one of the arguments used in support of PABP because it is based on an average price rather than on a marginal price which is volatile to gaming [31]. Another advantage with the PABP is that the risk for tacit collusion is lower in this mechanism compared to MP [11]. A drawback of pay-as-bid pricing is that market price does not reflect a surplus or deficit of the generation capacity and in the long-run it can deprive potential investors of receiving correct economic signals [21].

A number of recent studies have focused on the bidding behavior in the electricity markets and have compared the market performances under PABP and MP [30,12,11,21,22,27,15]. Wolfram [30] illustrated a simple electricity auction to examine the differences between discriminatory and uniform pricing auctions [30]. It is shown that for a typical case there are equal revenues from the discriminatory and the uniform pricing cases. Federico and Rahman [2003] compared uniform price and discriminatory auctions for perfect competition and monopoly. They demonstrated that the expected output decreases and the expected consumer surplus increases after a switch to PABP. Analysis in [11] concentrates on developing Nash equilibria for a duopoly model with constant marginal costs. It is shown that if the demand is inelastic and certainly known, the average prices will be lower under PABP. Ren and Gailana compared the quantitative behavior of a perfectly competitive market under PABP and MP structures [21,22]. For an uncertain demand, they demonstrated that although MP and PABP yield equal expected generator profits and consumer payments, the risk of not meeting the expected values is greater under MP. Game theory and auction theory are employed in [27] to analyze the strategic behavior of a two-player auction game under discriminatory and uniform pricing mechanisms. It is shown that the revenue equivalence theorem does not hold in a simple multiunit auction model in the presence of market power. Reference [15] develops an SFE model for a discriminatory auction and proves that SFE always exists if the system demand follows an inverse polynomial probability distribution. Given this probability distribution and compared to the uniform price auction, the demand-weighted average price is shown to be equal or lower in the discriminatory auction. Theoretical explorations of SFE have been attempted in [24] through relaxing assumptions of continuity of supply functions with focus on one-price payment rule. Reference [19] shows that discriminatory price auctions are preferable to the current practice of using uniform price auctions to determine spot prices. It demonstrates that under a discriminatory auction the supply curve is relatively elastic which reduces the price volatility caused by errors in forecasting total system demand.

In recent studies (e.g. [18,7,4,26]), the problem of strategic bidding is formulated as a bilevel optimization problem using SFE model, and an MPEC approach, introduced in [14], is used to solve the problem. For instance, reference [18] employs this technique to develop an optimum transmission expansion plan for a given power system when the gaming behavior of the power producers is taken into account. Reference [4] adopts the same framework to evaluate the performances of a typical power market with network constraints under strategic interactions amongst suppliers.

This paper characterizes the supply function equilibrium under PABP and MP mechanisms under imperfect competition with and without transmission limits. Strategic behavior of suppliers is represented via a parameterized SFE model involving manipulation of the sole intercept. The game problem is formulated as a bilevel optimization problem where each supplier solves an MPEC with the ISO's *Karush-Kuhn-Tucker* (KKT) conditions as constraints. For an unconstrained case, it is demonstrated that the optimal bidding strategy and the maximum profit of each strategic supplier, as well as the market clearing price are the same under PABP and MP mechanisms. However, this conclusion may not hold when transmission constraints and supply capacity limits are observed. Taking generators' random outages into account, the risk profile for each supplier is created through market simulation under PABP and MP mechanisms.

The remainder of this paper is organized as follows. Notations are introduced in Section II. Section III provides the mathematical problem formulation including the ISO and the supplier problems. The game solution technique and a methodology for constructing risk profiles are also presented in section III. Section IV is devoted to the simulation results of several case studies. Concluding remarks are presented in section V.

2. Notation

The notations used in this paper are introduced as follows. For a generic variable x, the notation x_i (for