Another Step Towards Equilibrium Offers in Unit Commitment Auctions with Nonconvex Costs: Multi-Firm Oligopolies

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Executive summary

We study the energy-cost ranking, offering behavior, and incentive properties of two uniform-price auction formats—centrally and self-committed—that are used commonly in wholesale electricity markets. Under both market designs, generators offer their supply into a uniform-price auction that is operated by an independent third-party market operator. The market designs are differentiated by the manner in which generators submit their offers and how generator-operating decisions are made. Given that these market designs are dominant in different parts of the world, we seek to understand better how the idiosyncrasies of each design impact offering incentives and expected settlement costs.

Under centralized commitment, a market design that is common in North America, each generator submits a complex offer containing its complete non-convex cost and operating-constraint information to the market operator. Then, the market operator uses these complex offers to make financially binding decisions regarding the commitment and dispatch of each generator by solving a unit commitment model, which is formulated normally as a mixed-integer optimization problem. In contrast, Western Europe and Australia employ self-committed markets. Under self commitment, generators submit simple offers that specify the price at which they are willing to supply energy. Taking the simple offers in merit order, the market operator generates a supply function, which is intersected with electricity demand to determine each generator's production level and the market-clearing price. Given the simple offers inherent to the self-committed market design, generating firms must internalize the non-convexities of their operating costs in their price offers. Centrally committed markets include a provision that each generator is made whole on the basis of its submitted offers, whereas no such guarantee exists in self-committed markets.

Given the debate surrounding the relative merits of these two market designs and the ongoing evolution of wholesale electricity markets, we contribute to the literature by studying a stylized model of oligopolistic competition and derive Nash equilibrium offering behavior under the two market designs. In doing so we extend the work of Sioshansi and Nicholson (2011), who study these market designs in a symmetric duopoly setting and determine that the market designs are expected-cost equivalent. We derive pure- and mixed-strategy Nash equilibria under the two market designs for different levels of demand and discover some striking differences with the duopoly model. We find that results with a multi-firm oligopoly are qualitatively similar to the duopoly case when demand is high. However, when demand is low, the two market designs are not expected-cost equivalent. Indeed, self-committed markets are expected to be costlier than centrally committed designs. This result is driven by the linear uniform prices of the self-

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committed market design. The use of make-whole payments under the centrally committed design introduces a discriminatory component to prices that allows for generators to recover their non-convex costs without impacting the revenues and profits that are earned by others. We include a numerical example to illustrate the mixed-strategy Nash equilibria. While stylized, this model establishes a framework for studying the idiosyncrasies of these market designs.

These findings have practical regulatory and policy relevance, as the lack of cost equivalence between the two market designs is not a result of one design being more prone to the exercise of market power than the other is. Indeed, when demand is high, which is the scenario in which firms have the greatest potential for the exercise of market power, the cost-equivalence result of the duopoly model holds. Our results illustrate a fundamental shortcoming of the use of linear uniform prices under a self-committed market design, an insight which may be of practical value in future regulatory and market-design debates. An important *caveat* of our work is that we do not consider the impact of these market-design choices on long-run investment decisions. The additional profits that are earned under a self-committed market design may be beneficial in the recovery of investment costs. On the other hand, these profits do not arise due to scarcity conditions. Rather, these additional profits stem from generators exploiting a deficiency in the remuneration mechanism that is used in self-committed markets to increase their profits.

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