ELECTRICITY MARKET STRUCTURE, WIND PENETRATION AND INFORMATION AGGREGATION: AN EXPERIMENTAL APPROACH

Cody Hohl, Ph.D. student, The Pennsylvania State University, cbh21@psu.edu
Anthony Kwasnica, Professor of Business Economics, The Pennsylvania State University, kwasnica@psu.edu
Chiara Lo Prete, Associate Professor of Energy Economics, The Pennsylvania State University, chiaraloprete@psu.edu
Feng Zhu, Assistant Professor of Economics, Nankai University, zf@nankai.edu.cn

Overview

Day-ahead energy markets are financially binding forward markets in which buyers and sellers bid to trade volumes of electricity for the coming day. In thermal-dominated electric power systems, one day is sufficient to forecast electricity demand with reasonable certainty and schedule commitments of power generation units, which take time to adjust. Increasing shares of wind and solar generation pose a challenge because day-ahead power forecasts are highly uncertain and may lead to inefficient scheduling of thermal units. For example, if the wind blows unexpectedly hard, some non-wind generation units that sold their production in the day-ahead market but turned out to be unnecessary in real time will burn fuel while sitting idle. Conversely, if the wind does not blow as expected, the shortfall in generation will need to be accounted for via fast start, expensive units in real time. Both outcomes are inefficient and may increase the need for uplift payments, or out-of-market payments to generation resources that ensure adequate compensation when they are ordered to produce or reduce power. Costs associated with forecast errors may become substantial, as penetration of renewable energy sources grows in electric power systems.

There are two approaches to this problem. In the United States, energy markets operated by Independent System Operators and Regional Transmission Organizations (henceforth, RTOs) have a two-settlement structure with coordinated day-ahead and real-time auctions. Since last-minute dispatch instructions can only make small changes to the day-ahead schedules, RTOs typically rely on intraday commitment processes to make more significant modifications in advance. Notably, these intraday processes do not produce financially binding prices, and thus do not provide economic incentives for wind units to solve their energy imbalances at the time they are foreseen. Further, the Federal Energy Regulatory Commission requires RTOs to forecast hourly production at all wind farms in their region. RTO forecasts are based on numerical weather prediction (NWP) models, combined with online measurement data (i.e., wind production and wind measurements at the farm) that are provided by the wind producers. The aggregate forecasts for the entire system are posted online to inform bidding decisions of market participants (FERC, 2012). Hence, U.S. RTOs aggregate and disseminate the local information owned by the wind units, and market participants make bidding decisions based on the aggregate result of the private information.

An alternate approach, which has emerged in Europe, relies on sequential intraday markets where participants could bid to sell more or buy out their forward positions, up to the time of actual physical delivery. In this case, there is no aggregation and dissemination of private information owned by the wind farms, as aggregate forecasts are not posted online. However, intraday markets produce financially binding prices that create economic incentives for wind units to settle their energy deviations as soon as possible. Thus, wind units are incented to do their best at forecasting their production schedules and adjust their forward positions in response to new information. It is worth noting that wind forecasts that rely more heavily on online measurement data would better account for local information, and thus may be more accurate than the forecasts made by the RTO. Ito and Reguant (2016) show that wind farms in the Iberian electricity market systematically adjust their forward positions in the intraday markets, and their position in the last market for a given hour is close to actual electricity production. As a result, non-wind units take opposite forward positions and progressively line up with how much they should produce in real time.

Could efficiency in U.S. power system operations be enhanced if market participants made decisions in intraday markets, instead of decisions based on the aggregate information posted by the grid operators? This talk will report the findings of an economic experiment that evaluates the comparative properties of two market structures: a two-settlement system akin to the one currently in place in the U.S., and a multi-settlement system with two intraday markets between the day-ahead and the real-time stage. We are especially interested in evaluating these designs in terms of their ability to reduce uplift payments.

Methodology

Experimental economic methods have proven to be valuable tools for evaluating efficiency gains from complex market structures, and have played a role in the design of wholesale electricity markets (Staropoli and Julien, 2006). For example, Rassenti and Smith (1986) conclude that electricity markets organized as double-sided auctions where allocation is determined according to physical properties of the grid would be feasible and efficient. Their work also emphasizes the role of demand-side bidding in reducing market power in electricity markets, as confirmed by other laboratory experiments (Denton et al., 2001; Rassenti et al., 2002).

Another strand of the literature compares institutional arrangements for electricity auctions to answer questions related to the performance of uniform price vs. continuous auctions (e.g., Bernard et al., 1998), and uniform price vs. discriminatory price auctions (e.g., Rassenti et al., 2003). Several studies have addressed issues related to network constraints and market power (e.g., Brandts et al., 2013), the impact of price caps in a multi-unit uniform price auction (Kiesling and Wilson, 2007) and the effects of increasing market-wide price caps and introducing a capacity market on investment (Le Coq et al., 2017). We are not aware of any experimental studies that examine information aggregation and the interplay of private and public information in electricity markets.

We design and conduct laboratory experiments for making judgments about the comparative properties of wholesale electricity market structures to support wind energy penetration. Each experimental session is divided into a sequence of independent market days, and each market day consists of several stages, depending on the market structure. Subjects play the role of generation units that supply electricity into the market for a given day. Generators may be of two types (wind and non-wind), and place an offer quantity and an offer price at each market stage. Electricity demand is perfectly inelastic and common knowledge. The aggregate wind forecasts for the entire system at each stage are also available to all market participants. In addition, wind generators are provided with a private signal representing the wind forecast at a given stage. After everyone has submitted their offer quantity and price at each stage, the market takes all submitted offers and selects the combination of offers that satisfies the expected electricity demand at the lowest cost, subject to network and generator constraints.

Preliminary results

We are conducting experimental sessions that consist of six independent trading days under varying market conditions. Our first treatment variable is the market structure: two-settlement (TS) or multi-settlement with two intraday markets (MS). Depending on the market structure, each trading day consists of a different number of stages (two in the two-settlement structure, and four in the multi-settlement structure). Each market structure is examined under identical parameters (e.g., cost and demand structures) and identical information (i.e., we study what would happen if we created a MS structure with the same information features as the TS structure). We plan on conducting experiments on two additional treatment conditions, information revelation and wind energy penetration. In the information revelation treatment, we will assume that private forecasts of individual wind farms are more accurate than the RTO forecasts. In addition, market participants will make bidding decisions based on the aggregate RTO forecasts in the TS structure, and on the aggregate private forecasts in the 2S structure. This is intended to reflect changes in bidding behavior resulting from different information revelation in the two structures, as in real-world market designs. In the wind penetration treatment, we will examine performance of the market structures as the share of wind energy in the system increases.

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