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Can market power in the electricity spot market translate into market power in the hedge market?☆

Gabriel Godofredo Fiuza de Bragança[a,b,*], Toby Daglish[c]

[a]Instituto de Pesquisa Econômica Aplicada (IPEA), Brazil
[b]IBMEC, Brazil
[c]Victoria University of Wellington, New Zealand

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ABSTRACT

Electricity is a non-storable commodity frequently traded in complex markets characterized by oligopolistic structures and uniform-price auctions. Electricity prices have idiosyncratic patterns not addressed by the usual commodity pricing literature. This paper develops an electricity market model that allows for oligopoly, vertical integration, and a uniform-price auction mechanism. It derives a linear equilibrium relationship between spot prices and state variables affecting firms' costs and demand. It then applies a two-factor forward pricing model over the equilibrium spot price process, and shows that forward prices can be positively affected by spot market power. An empirical estimation of the model follows, using NZEM data.

1. Introduction

A large portion of the energy traded in most competitive electricity markets is hedged. Forward and futures contracts frequently constitute the most significant hedging instruments. This paper presents a model that can be used to evaluate how concentration in the electricity generation industry impacts the forward price curve. Our hybrid pricing model also innovates by taking into account common features of electricity markets, such as oligopoly, forward contracts, vertical integration, and a uniform price auction mechanism.[1] We analyze how an increase in spot market concentration can increase (or decrease) prices in the hedge market.

Electricity is a non-storable commodity for which spot prices are characterized by the presence of strong seasonal patterns and short-lived trend deviations (spikes). Several papers start from these

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* Corresponding author.
E-mail address: gabriel.fiuza@ipea.gov.br (G. Fiuza de Bragança).

[1] Papers such as Allaz and Villa (1993), Newbery (1998), Green (1999) and Bushnell (2007) using Cournot or supply function equilibrium (SFE) frameworks observe the importance of forward contracts in reducing market power. On the other hand, Ferreira (2003), Mahenc and Salanie (2004), Liski and Montero (2006) and Green and Le Coq (2010) find opposite results using Bertrand models or focusing on the dynamic aspects of contracts.

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premises and take into account a broad array of stochastic processes to mimic observed price behavior. They mostly rely on assumed storage possibilities and make use of no-arbitrage arguments to value derivatives. Schwartz (1997), Schwartz and Smith (2000), and Lucia and Schwartz (2002) concentrate on mean reverting behavior, long-term uncertainty, and seasonality. On the other hand, Deng (2000) and Cartea and Villaplana (2005) focus on short-lived oscillations such as jump and spike features. However, these papers frequently rely on estimating non-observable state variables, which is costly in terms of data quality and availability. Few equilibrium insights can be drawn from either of these models.

To overcome these disadvantages, a growing literature applies hybrid models to price derivatives. These models are composed of two basic stages. First, they build on an equilibrium framework when explaining electricity price behavior in terms of observable state variables of demand and supply. Second, they assume a dynamic behavior for state variables and apply no-arbitrage methodologies to price derivatives. This approach offers economic insights into derivative pricing. In other words, derivatives are priced in terms of demand and supply parameters. Skantze et al. (2000), Barlow (2002), Pirrong and Jermakyan (2008), Cartea and Villaplana (2008) and Lyle and Elliott (2009) are representatives of this line of research. All these models are characterized by imposing a functional form, based on equilibrium assumptions, for the relationship between price and variables related to demand and supply. Barlow (2002) considers the existence of deterministic and strongly increasing marginal production costs and a stochastic aggregate demand. Skantze et al. (2000) consider the spot price as an exponential function of load and supply bid shifts, treated as stochastic, and calculated through principal component analysis. Pirrong and Jermakyan (2008) also propose modeling the equilibrium price as a function of two state variables. The state variables are given by electricity demand and the futures price of the marginal fuel, where electricity prices are an increasing function of demand. Cartea and Villaplana (2008) use an exponential function of two observable state variables: demand and generation capacity. They assume that electricity prices are increasing in demand and decreasing in capacity, and propose a closed-form pricing model for forward prices taking into account seasonality and heteroskedasticity. Lyle and Elliott (2009) build on Cartea and Villaplana's model and use more sophisticated supply assumptions. They also improve the estimation procedures and derive a closed form solution for European option prices written on average spot prices.

All the aforementioned models implicitly assume competitive markets and a pay-as-bid pricing mechanism without explaining if it is a good approximation for markets with more complex structures. None of these derivative models address central aspects of many wholesale electricity markets: market power, vertical integration, and a uniform price auction design. This paper addresses how more realistic market structure can affect hybrid pricing modeling.

To evaluate the bidding behavior of generators, Hortacsu and Puller (2005, 2008) develop a one-period equilibrium model that deals with electricity spot price formation in markets characterized by oligopoly and uniform price auction design.[2] We adapt their model to take into account demand and supply shifters, and to allow for vertical integration. The result is a theoretically well founded linear relationship between spot price and state variables. We then apply the Lucia and Schwartz (2002) two factor arbitrage pricing results along with our spot price formation model to calculate a closed form solution for forward/futures prices. We evaluate how hedge prices are affected by the market structure and the dynamics of state variables. Most importantly, we show how spot market power affects the hedge market. We also use our forward pricing model to analyze the New Zealand Electricity Market (NZEM).

The remainder of this paper is organized as follows. Section 2 presents and discusses our equilibrium spot price model. Section 3 presents our hybrid pricing application to evaluate forward prices and the role of spot market power. Section 4 exhibits an empirical exercise where the NZEM is analyzed. Section 5 concludes.

2. Spot price model

2.1. Assumptions

The wholesale market is oligopolistic, and firms can be vertically integrated (gentailers). The electricity market has N total firms comprising K generators, R retailers and I gentailers. The wholesale spot price at any given time is determined through a uniform price auction, where generators submit an individual supply schedule, and an auctioneer clears the market. Aggregate consumer demand and generator cost functions are influenced by a set of state variables assumed to be known at the moment of the auction. State variables change over time and cause shifts in demand and supply. A retailer's revenue is determined by an exogenous retail price and the particular retailer's market share of aggregate consumer demand. The only source of uncertainty at the time of the auction for a given generator is its rivals' forward positions and the prices of these contracts. Both the contract positions and prices are assumed to be exogenous.

Definition 2.1. State variables are represented by the L-dimension state variable vector $\vec{W}_t = \{w_{1t}, w_{2t}, \ldots, w_{Lt}\}$, which is assumed to be exogenous and known by all firms at time t.

Definition 2.2. Consumer aggregate demand at time t is defined by the function $\tilde{D}_t = D_t\left(p_t^R, \vec{W}_t\right)$. Retail price p_t^R is assumed to be exogenous.

Aggregate retail demand is only affected by the state variables $\vec{W}_t$ and the retail price p_t^R. At the time of the auction, the demand function is deterministic. This definition is equivalent to assuming that instantaneous demand shocks are negligible. Uniform-price auctions used to clear electricity spot markets have a very short-term horizon. Bids into uniform price electricity auctions are made for delivering energy close to dispatch. In markets such as the NZEM, the bid can be modified until 2 hours prior to the delivery time. The more significant source of uncertainty for a specific bidder at the time of the auction is the hedging position of its rivals.

One obvious implementation of this model would be to say $D_t = w_{1t}$. However, more generally, we can also think in terms of demand shifters such as income, economic activity, institutional changes, seasonality or climate factors, each of which has separate effects on demand. The assumption of exogeneity of p_t^R is a good approximation for electricity markets for two reasons. First, retail prices are frequently regulated. Second, even when retail prices are freely determined, contracts between retailers and customers usually have a long-term nature. In other words, it is not reasonable to assume that retailers react to each instantaneous oscillation in the spot market when deciding the price they charge their consumers.[3]

[2] Their model produces a theoretical ex-post optimal result. We consider it reasonable to assume that players behave optimally for our hybrid pricing purposes. The authors concentrate, however, on the empirical task of comparing the actual bidding behavior in the Texan (ERCOT) electricity market to their theoretical benchmark. Their empirical findings (that big generators, with relevant participation in the market, perform closely to their theoretical model) reinforce our choice.

[3] In reality, retail and industrial prices are frequently not the same. However, to keep the model simple, we consider just one aggregate demand affected by retail prices.