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The impact of expansion of wind power capacity and pricing methods on the efficiency of deregulated electricity markets

Ofir D. Rubin [a,*], Bruce A. Babcock [b]

[a] Department of Public Policy and Administration, Guilford Glazer Faculty of Business and Management, Ben-Gurion University of the Negev, P.O. Box 653, Beer-Sheva 84105, Israel

[b] Department of Economics, Iowa State University, IA, USA

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ABSTRACT

The remarkable expansion of global wind power capacity in many countries brings forward several key economic questions regarding the performance of impacted electricity markets. Wind forecast uncertainties and rules that penalize scheduling deviations often discourage wind energy producers from participating in day-ahead electricity markets. Instead, wind energy commonly is priced either in the real-time balancing market or via a Feed-in-tariff (FIT) arrangement. In this paper we extend a recently developed equilibrium modeling approach to examine how the integration of wind energy impacts premiums in day-ahead electricity markets. In particular, we compare premiums as wind power capacity expands for different pricing mechanisms. By considering operational costs related to ramping conventional generators we are able to characterize the efficient level of premium needed to cope with the intermittent nature of wind. We find that the way that wind energy is priced is critical. We show that in the presence of imperfect competition pricing wind energy in the market increases firms' ability to extract oversized day-ahead premiums while in the case of market-independent FIT, market power is reduced as wind power capacity expands.

1. Introduction

Integrating renewable energy into trade at the wholesale electricity markets is a challenging task. Unlike conventional power units, electricity production from renewable energy fluctuates over time as output depends on precipitation, radiant energy and air flows which are uncertain by nature. Technically, transmission system planners seem to be able to identify and to take steps to relieve bottlenecks to integration of renewable energy such that system reliability is not compromised. In contrast, the impact of renewable energy on the efficiency of electricity markets has not yet been studied comprehensively. The variable nature of renewable energy implies that they cannot be marketed in the same way that conventional power is marketed. Particularly, wind power is of great interest as its variability makes it the most difficult energy resource to integrate into the power system [1] and yet, wind power has been recently established as a major source of renewable energy (see Fig. 1).

A typical wholesale electricity market administers trade via a two-settlement process that includes one market for short term forwards (i.e. day-ahead or hour-ahead market) and one real-time market for balancing power. Most markets make use of uniform price auctions in which the market clearing price is determined by the bid of the marginal megawatt hour (MWh) of electricity produced by the marginal power generator. This mechanism promotes efficiency by encouraging generator firms (GFs) and Load Serving Entities (LSEs) to bid their true marginal costs and marginal willingness to pay, respectively (for a state-of-the-art review on this subject see Ref. [2]).

Policies that price wind energy can be divided into two types: those that price wind energy inside the market or those that price it outside the market. The former is widely used in North America where wind energy is priced directly in the market. For example, a recently adopted regulation in two regions in the United States is for the system operator to integrate all available wind energy in real-time using an economic dispatch. This means that in these regions wind power generators are obliged to participate and are treated like any other generation resource in real-time energy markets.[1] Pricing wind energy (and other renewables) via a feed-in tariff (FIT) mechanism is commonly used in Europe. This mechanism typically guaranties generators with a fixed price for 15–20

[1] In 2009, New York ISO (NYISO) became the first grid operator in the United States to integrate all wind energy in real-time for balancing the reliability requirements of the power system [37]. On June 2011 similar regulation has been put forward by the Midwest Independent Transmission System Operator (MISO), which manages one of the world's largest electricity markets using security-constrained economic dispatch of generation.

* Corresponding author. Tel.: +972 8 6472251; fax: +972 8 6472816.
E-mail address: orubin@bgu.ac.il (O.D. Rubin).

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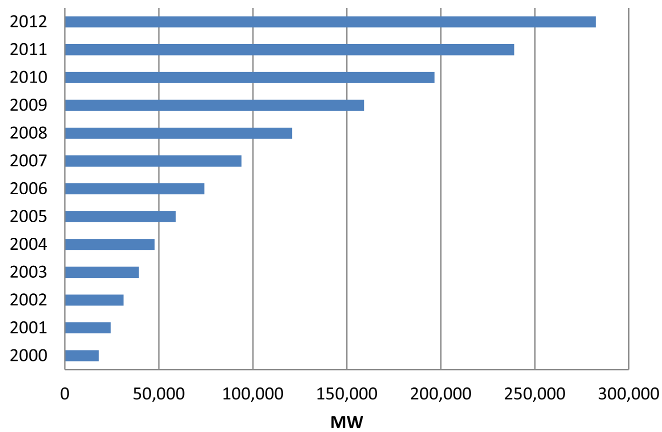

Fig. 1. World total installed wind power capacity. (Source: World Wind Energy Association).

years. Often, a wind energy producer paid a FIT, has to allow the system operator to sell its electricity in the day-ahead market. Then, the system operator is obliged to pay the producer the FIT rate regardless the realized spot price. In this case, although indirectly, wind energy is still traded and priced in the market. In practice there are more pricing schemes for wind power capacity output. A detailed country-specific survey of wind energy policies can be found in Ref. [3]. In this study we focus on two policies which represent quite different approaches—pricing wind energy in the market or via a market-independent FIT.

Integration of wind energy has two direct effects on electricity wholesale markets. First, once wind capacity is installed, its generation cost is negligible compared to the costs of balancing power by conventional generators in real-time. Therefore, when available, wind energy is used before conventional units which suppress real-time prices [4–9]. Second, the intermittent nature of wind energy increases the frequency with which the output of conventional units is adjusted, thereby increasing operational costs of generators (see for example [10,11]).

One unintended impact of public support for investments in wind energy is that spot prices may be depressed to a point that market incentives to invest in conventional generators are too low [6,7,12]. In the presence of market power, the picture is quite different. Ref. [13] shows that the emergence of wind energy in the form of fringe capacity allows large firms to amplify the effect of intermittent supply on market prices. This result is caused by large firms depressing prices when they need to buy back energy and increasing prices from their conventional units when wind power supply is low. Ref. [14] provides empirical support for this result, showing that conventional generators gain more than wind power producers as market concentration increases.

Policies that prioritize wind energy over conventionally-generated electricity are designed to promote deployment of renewable energy resources. But the feasibility of continuing such policies at high wind penetration rates is unclear. In this paper we extend a recently developed theoretical framework to allow the modeling of wind-integrated electricity markets. In doing so, we account for the decrease in the use of conventional power generators due to the availability of wind energy. Also, we model firms' risk management behaviors in the day-ahead market, which are strongly influenced by the new uncertainty introduced by wind from the supply side of the market. Our analytical work provides transparent, traceable and robust results for equilibrium measures of electricity markets with wind energy. The theoretical framework is used to analyze two mechanisms for pricing wind energy and to make numerical measures of market performance as wind power capacity increases. The simulation of the spatial nature of wind power in this paper is an original application of the method for imposing correlations first proposed by Iman and Conover in 1982 [15].

Our model confirms that electricity prices fall as wind power penetration rate increases. Moreover, accounting for the costs associated with ramping conventional generators, we are able to model the required price increase due to the uncertainty of wind power supply. In accordance, we define in this study efficient electricity market as one that creates the proper incentives (i.e. day-ahead premiums) to secure the required investments in conventional generators. The comparison between the two mechanisms for pricing wind energy yields quite different results with respect to day-ahead market premium. When wind is priced in the market we observe a steep increase in the day-ahead premium. Because buyers are paying for all electricity in the market, they are fully exposed to the volatility of real-time price. Sellers, in turn, can further take advantage of their market power. When wind energy is owned by fringe firms, premiums are a bit lower but still much higher than the premium that arises solely from firms hedging against real-time energy shortages. In contrast, when a market-independent FIT is used to price wind energy day-ahead premiums are slightly reduced. Because compensation for wind energy does not relate to market operations, buyers' exposure to real-time pricing is limited to the residual load supplied by conventional generators. This in turn reduces their willingness to pay in the day-ahead market. On the downside, in relatively less concentrated markets, as wind capacity expands this pricing mechanism may drive forward premiums too low to induce optimal investments in new conventional generation capacity.

The remainder of this paper is organized as follows. In Section 2 we present the modified equilibrium approach for modeling wind-integrated electricity markets. This includes an extension of a previous theoretical framework to allow the model to handle the two mechanisms for pricing wind energy and to allow for a degree of freedom in the ownership type of wind power capacity (e.g. oligopolistic/fringe). In Section 3 we explain the numerical example of electricity markets with respect to wind energy penetration rate, industry structure and the way wind energy is priced. An essential part of the simulation is the ability to impose spatial correlation on wind in the analysis. We achieve that by an original application of the Iman and Conover (1982) methodology. Section 4 presents and discusses our simulation results. Section 5 concludes our projections regarding the differences between the two mechanisms for integrating wind power into wholesale electricity markets.

2. The model

We extend the equilibrium electricity market model developed by Ref. [16] (henceforth RB, 2011) to account for the availability of wind power capacity. The theoretical framework is suitable for consideration of wind energy integration for several reasons. First, it is a double-sided auction model thus it accounts for the behavior of Cournot firms on both sides of the market (i.e. LSEs and GFs).[2] Second, the model provides equilibrium measures of the two-settlement process which reflects the trade mechanism adopted by many deregulated electricity markets in the world. In particular, we use RB (2011) terminology that refers to the two wholesale markets as the day-ahead forward market and the spot market.[3]

[2] The Cournot competition approach is widely applied in electricity market modeling (see e.g., [40–43,45]).

[3] In Europe, people often refer to the day-ahead and real-time market as spot and balancing market respectively. However, to avoid confusion we adopt the terms (and subsequent notations) which are used in RB (2011) and describe the terminology frequently used in North America.