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An equilibrium pricing model for wind power futures

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ABSTRACT

Generation from wind power plants is intermittent and affects profits of wind power generators and conventional generators alike. Currently, generators have limited options for transferring the resulting wind-related volume risks. The European Energy Exchange (EEX) recently introduced exchange-traded wind power futures to address this market imperfection. We propose a stylized equilibrium pricing model featuring two representative agents and analyze equilibrium prices as well as the mechanics behind risk premia for wind power futures. We calibrate and simulate stochastic models for wind power generation, power prices, electricity demand, as well as other relevant sources of uncertainty and use the resulting scenarios to conduct a case study for the German market; analyzing prices, hedging effectiveness, and risk premia. Our main result suggests that wind generators are willing to pay an insurance premium to conventional generators to reduce their risks. We conduct a thorough sensitivity analysis to test the influence of model parameters and find that our results on risk premia hold for a broad range of reasonable inputs.

1. Introduction

The energy industry has historically been one of the most weather-sensitive sectors in the economy as temperatures throughout the year drive the demand for power and natural gas. This situation has been greatly exacerbated by heavy investment into weather-dependent renewable energy generation in the recent years, which is instrumental in reducing future greenhouse gas emissions. Intermittent power generation technologies such as wind power and photovoltaic constitute the major share of current renewable installations, and projections indicate their continued growth in the future (IEA, 2014).

In some countries, such as Germany or Denmark, the share of wind power has already reached considerable levels. This development has introduced substantial weather risks to the supply side of the energy industry resulting from stochastic wind speeds, which determine wind power generation volume in any particular period. Fig. 1 displays capacity factors, defined as ratio of average generation volume over installed capacity, illustrating that wind generation in Germany is highly volatile even for longer observation periods such as months and years.

The resulting volume risk faced by owners of wind power plants is currently not tradable via standardized products on energy exchanges. Consequently, wind power producers cannot sell this risk to other market participants who might be in a better position to take it, inducing inefficiencies and ultimately welfare losses. For this reason, *wind power futures* have recently been introduced by the European Energy Exchange (EEX). The underlyings of these futures are capacity factors for the average German wind power plant, i.e., the risk-neutral prices for a contract are naturally bounded between 0 and 100. The futures holder receives a payment which is equal to the actual observed utilization in a given month, quarter, or year. Consequently, the futures can act as an instrument to hedge risks emanating from volatile wind generation volume.

In this paper, we investigate the determinants of the price of these futures contracts and the structure of potential risk premia in the market. These aspects are highly relevant to wind power and conventional generators, as well as every other agent with an interest

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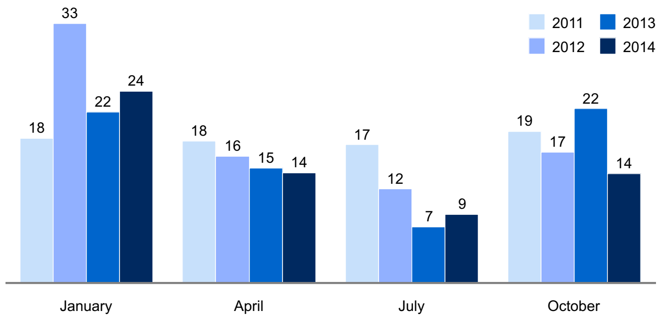

Fig. 1. German monthly wind capacity factors in percent from 2011 to 2014 for four example months January, April, July and October.
Source: Generation data in 15 minute intervals were obtained from the four German transmission system operators 50Hertz, Amprion, Tennet, Transnet and daily capacity data from Deutsche Gesellschaft für Sonnenenergie (2015) .

to trade wind futures. In our analysis, we seek to estimate expected payoffs accurately and try to understand potential risk premia.

There essentially exist three distinct streams of literature concerned with pricing futures contracts: applications of the rational expectation hypothesis (REH), no-arbitrage pricing, and equilibrium models. The REH states that the price of a futures contract is equal to the discounted expected spot price, or in case of wind power futures, the expected capacity factors in Germany (see Fleten and Lemming, 2003; Burger et al., 2004, for examples of models for power futures). The REH assumes risk-neutral decision makers and therefore precludes risk premia whose existence in power markets is well established (see Longstaff and Wang, 2004; Weron, 2008; Kolos and Ronn, 2008; Huisman and Kilic, 2012; Redl and Bunn, 2013).

No-arbitrage pricing approaches on the other hand, identify a risk-neutral probability measure and an associated market price of risk. Hence, they do consider risk premia but cannot explain their mechanics and interaction with the position holders' business model. Furthermore, the underlying of wind power futures is not tradable until maturity. Hence, no-arbitrage pricing approaches based on replication arguments are not directly applicable (see Pirrong and Jermakyan, 1999; Eydeland and Geman, 1999, for the structurally similar case of power futures). We only know of one other paper that has proposed a pricing model for wind futures. Benth and Šaltyte Benth (2009) developed a no-arbitrage pricing approach for futures based on an index of aggregated wind speeds, which were launched on the US Futures Exchange in 2007. The authors model wind speeds dynamically applying a continuous-time autoregressive model with seasonal mean and volatility. They derive futures prices and demonstrate that their volatility shows an unexpected development over time.

A detailed analysis of risk premia's size, structure, and drivers is possible with equilibrium models. Equilibrium models capture the fundamental economic rationale of risk-averse market participants, which allows to explain their trading behavior and the resulting premia (see Allaz, 1992; Allaz and Vila, 1993; Bessembinder and Lemmon, 2002; Bushnell, 2007; Bushnell et al., 2008).

Consequently, as this model class is best suited for our analysis, we develop an equilibrium model for wind futures valuation to understand prices and risk premia. More specifically, we adapt the model by Bessembinder and Lemmon (2002), who analyze the equilibrium between two representative agents on the power market. To the best of our knowledge, the present paper is the first application of an equilibrium model to the valuation of a weather derivative. Thereby this paper links two disjoint bodies of literature and contributes to the overall understanding of pricing derivatives without a tradable underlying. In our case, the two representative agents are defined as the owner of a wind power plant and a conventional generator. In the resulting mean–variance expected utility framework we can define utility-maximizing futures positions in dependence on the futures price. These optimal supply curves allow us to derive a closed-form solution for the futures' equilibrium price and quantity.

Let us mention that there are a range of stochastic optimization approaches that model the decisions of risk-averse agents on electricity markets assuming that prices are exogenous, i.e., companies are price-takers. These papers are usually concerned with optimal hedging, investment, and operational decisions and use detailed modeling of the firms' circumstances (Hochreiter et al., 2006; Kettunen et al., 2011; Pineda and Conejo, 2012; Gersema and Wozabal, forthcoming). While the aim of these papers is fundamentally different from our aim of explaining market prices and risk premia, important lessons can be learned from studying risk-averse decision making. In particular, looking at the abovementioned papers, it becomes clear that physical risks in the electricity markets cannot be fully hedged using the available instruments on the energy-only markets. This underlines the requirement for non-standard instruments such as wind power futures that allow for trading of physical risks and thereby contribute to more efficient allocations of risk in energy markets.

As the proposed wind power futures will be introduced in Germany, we use the German market in our simulation-based case study. However, the proposed methods and fundamental results are of a general nature and carry over to other countries as well.

We use our model to determine the sign of the wind futures' risk premia as well as the determinants of these premia in thorough sensitivity analyses. We find that wind power futures are likely to be traded at a discount for a broad range of input assumptions, i.e., the wind power producer is ready to sell the contracts at a price below the expected capacity factor, which leaves the conventional producer with a positive expected profit from the transaction.

We conduct an extensive sensitivity analysis to explore the range of prices and discounts that might arise in the market for wind futures. Additional contributions are an examination of the hedging effectiveness for exemplary wind generators and a detailed analysis and simulation of wind capacity factors as the underlying risk factor.

The paper at hand is structured in six sections. Section 2 describes the role of wind-related risks in the energy industry and the proposed wind futures. Section 3 discusses the chosen equilibrium model including the agents' profit functions. Section 4 gives details on the underlying simulation models and data assumptions for our case study. Section 5 reports model results regarding equilibrium prices, premia and quantities as well as sensitivity analyses. Section 6 concludes the paper.

2. Wind-related risks and the new wind power futures

2.1. Players, their risks, and the need for wind power futures

We focus on two groups of firms, which are strongly affected by volatile wind generation: *wind power generators* and *conventional generators*. The former profits from more wind power generation while the latter profits from less wind power generation as will be argued in the following.

For *wind power generators*, uncertainty in wind generation volume manifests in three distinct forms of risk. First, pre-investment forecasts of long-term wind speeds could be wrong resulting in volumes consistently below the expected level over the whole lifetime of the investment. Secondly, risk is induced by medium-term volatility of wind power generator's volume from period to period. Lastly, wind power producers active on power exchanges face the short-term risk of committing wrong quantities on the day-ahead market resulting in balancing costs. In this paper, we focus on the second type of medium-term risk that is concerned with revenues for several weeks to a maximum of three years.