Wind Power and the Electricity Market for Upward Regulation: Evidence for Western Denmark

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Overview

The production of electricity from wind is highly dependent on wind levels which make the dispatch of this energy source significantly uncertain. Since the stability of an electricity grid requires that the supply of power equals load, this can impose costs on the system as highly dispatchable but costly sources of electricity supply are dispatched to compensate for the change in wind power.

In this paper we examine the market impact of changes in hourly wind power on both the deployment and the price of upward regulation, upward regulation being the power dispatched by system operators to alleviate shortages of electricity. The analysis focuses on Western Denmark, a power grid where wind power accounted for approximately 23.5 percent of load in 2004, the latest year for which complete data are available.

Methods

We use data from Eltra, the former system operator of the electricity grid in Western Denmark over the period from January 2004 to March 2005. The former provides hourly information on the electricity market in Western Denmark, including price, consumption (load), primary, local and wind production, quantity of trade with other members of the Nord Pool system and the relative price, and the unbalance between demand and supply. This is the focus of our analysis. In fact, although demand and supply balance in the day ahead forecasting, actual production and consumption may vary unexpectedly and the system operator may need to buy extra-capacity from by-standing producers in order to avoid shortages. The premium over the day-ahead price paid to last-minute producers is the cost of upward regulation.

Upward regulation is required in 58 percent of the hours in the period covered by our sample. In these cases, upward regulation amounts to about 6 percent of total load. In the same period, wind power provides about 25 percent of total production of electricity. The average day-ahead price of one MWh of electricity is 211 Danish Crowns (DKK). In case of upward regulation, the surcharge amounts on average to 28 DKK – i.e. to more than 10 percent of the Elspot day-ahead price.

We first assess the impact of wind power variability on the quantity of upward regulation ($RAMPUP_t$, expressed in MWh). The following factors are included in our econometric model.

Variation in wind power production. Increases in wind power production make upward regulation less likely, while the opposite holds for sudden drops. This is the focus of our analysis. As the effect of increases and drops is not necessarily symmetrical, in our model we include two separate variables, one for positive changes in the last hour ($POS\Delta W_t$), and one for the absolute value of negative variations ($NEG\Delta W_t$). Both variables are censored to zero when the quantity of wind power varies in the opposite direction.

Level of wind power production. High levels of wind power production make upward regulation less likely. Therefore, we control for the quantity of electricity from wind produced one hour earlier ($WIND_{t-1}$),

Load and Changes in Load. High levels or sudden increases in consumption make upward regulation more likely, as the system operator is forced to look for extra-capacity in order to avoid an excess of demand. We consider two variables, measuring the quantity of load one hour earlier (L_{t-1}), and its variation in the last hour (ΔL_t).

Known Transmission Constraints within Nordpool. The power grid in Western Denmark is a member of Nordpool, the Nordic Electric Power market (http://www.nordpool.com). It is likely that the incidence of upward regulation in Western Denmark will be lower (higher) when the transmission system between Western Denmark and its trading partners is unconstrained (constrained). To the extent that these constraints are known, they will be reflected in the day-ahead Elspot prices. Accordingly, the natural logarithm of the day-ahead Elspot price for Western Denmark relative to Nord Pool's system-wide price will be used as an explanatory variable ($PriceRatio_t$).

Temperature and Air Pressure. Because both steam and gas turbines are "air-breathing" engines, their performance is affected by both ambient temperature and air density. Based on these considerations, we expect that the deployment of upward regulation will increase with increases in ambient temperature ($TEMP_t$) but decline with increases in atmospheric pressure (AIR_t).

Other Factors. There are obviously other factors that can influence both the probability of an upward deployment of regulation as well as its magnitude. We control for their possible influence through the use of binary variables. Specifically, the econometric model will include binary variables to each month of the sample period (M). Finally, we include time dummies for each hour of the day (H), as proxy of different characteristics of the electricity market not captured by other variables.

As the dependent variable is censored to zero, we estimated the quantity of upward regulation using the Tobit specification. The empirical results indicate that a drop in wind power production significantly increases the amount of upward regulation. The marginal effect on the unconditional expected value is equal to 0.34, meaning that a drop in wind power by 1 MWh increases upward regulation by 0.34 MWh. Unexpectedly, an increase in wind power does not seem to decrease the amount of upward regulation. The relative coefficient is positive, although not statistically significant. More research is needed to understand the asymmetric effect of increases and decreases in wind power production.

High levels of (lagged) wind power production reduce the amount of upward regulation. Symmetrically, load has a positive and significant effect on upward regulation, while the coefficient on the change in load from the previous hour is not statistically different from zero.

Air temperature is positively correlated with upward regulation, although the effect is not statistically significant. Increases in air pressure significantly reduce the quantity of upward regulation, by making gas turbines more efficient.

With the observed path of wind power variability, our model predicts on average 90.25 MWh of upward regulation. When wind power variations are set to zero, the average level of upward regulation drops to 79.54 MWh. On average, our findings suggest that 12 percent of the quantity of upward regulation is due to variation in wind power supply. Preliminary evidence suggests that the variability in wind power production increases the price of upward regulation by about 9 percent

Conclusions

This study has examined the impact of the variability in wind production on both the quantity and price of upward regulation in Western Denmark over the period January 2004 through March 2005.. The preliminary findings indicate that the impact is nontrivial.

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