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## ***RESIDUAL DEMAND MODELING AND APPLICATION TO ELECTRICITY PRICING***

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### **Overview**

Worldwide the installed capacity of renewable technologies for electricity production is rising tremendously. The German market is particularly progressive and its regulatory rules imply that production from renewables is decoupled from market prices and electricity demand. Conventional generation technologies are to cover the residual demand (defined as total demand minus production from renewables) but set the price at the exchange. This results in negative prices and peak-shaving. Existing electricity price models do not account for the new risks introduced by the volatile production of renewables and their effects on the conventional demand curve. An extension to the class of supply/demand models (also known as hybrid models) is proposed to account for renewable infeed in the market. Infeed from wind and solar (photovoltaics) is modeled explicitly and withdrawn from total demand. The residual demand is used as an input to the supply-side of existing models to determine the electricity price. In a case study the model is applied to the German electricity market.

### **Methods**

The methodology in modeling renewable infeed is to separate the impact of weather and capacity, respectively. Efficiency (=load factor) of the renewable technology depends on the weather conditions and is modeled as a stochastic process. It is defined as actual infeed divided by installed capacity and therefore takes values in  $[0, 1]$ . A logit-transformation is applied to allow for stochastic processes supporting the whole real line. Installed capacity is assumed as a deterministic function of time (obtained from market information). For wind efficiency an Ornstein-Uhlenbeck process with a seasonal mean-reversion level is proposed as it provides a good fit of the empirical distribution. Solar infeed shows a very strong intra-day pattern, which has considerable impact on market prices in peak hours. To account for this pattern the daily maximum efficiency is modeled and transformed to the single hours using a time-dependent deterministic function. For the daily maximum an Ornstein-Uhlenbeck process with a seasonal mean-reversion level is used. In a case study the residual demand model is applied to the German day-ahead market using a simple supply/demand model similar to Barlow (2002). The year 2012 is simulated with an hourly resolution based on a calibration using historical data of wind and solar infeed, realized load and spot prices. For comparison, the model is also calibrated on the quarterly futures for delivery in 2012 traded on the EEX.

### **Results**

Model simulations show the typical features seen in market prices in recent years. Hardly any positive spikes appear in price trajectories for spring and summer (due to simulated infeed from solar plants). In winter (low solar infeed) moderate positive spikes are obtained on days with low wind infeed, but high demand. On days with low demand and high wind infeed the model produces negative spikes, which is a prevailing feature in market prices. Moreover, forward prices are calculated and compared to market data. Simulated prices from the spot calibration are lower than market future prices, which has been expected due to the uncertainty in the German market about the effects of the partial nuclear phaseout in 2011. Calibration on futures leads to prices close to observed futures, even though the term-structure cannot be matched perfectly due to the limited number of parameters in the model. It is found that renewable infeed increases the volatility of forward prices in times of low demand, but can reduce volatility in peak hours. Prices for European options on baseload futures are calculated based on the futures-calibration. A comparison to quoted market prices reveals that the model performs well also on the tails of the price distribution. Moreover, prices for different scenarios of installed wind and solar capacity are compared and the merit-order effect of increased wind and solar capacity is calculated. It is found that wind has a stronger overall effect than solar, but both are even in peak hours.

### **Conclusions**

The proposed model is suited to extend existing models to account for infeed from renewables. The calibration on renewable infeed data extends the data pool for the model and reduces the risk of overfitting. The case study shows that typical features of market prices are reproduced and the risk inherent in the volatile production of renewables is captured.

### **References**

Barlow, M. (2002), 'A diffusion model for electricity prices', *Mathematical Finance* 12: 287–298.