The stabilizing effect of hydro reservoir levels on intraday power prices under wind forecasting errors

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The daily power system has to deal with three main sources of uncertainty:

- Demand uncertainty and load prediction errors
- Failure of power plants
- Uncertainty of wind
Effect of windpower on power prices

- Renewable resources produce lower wholesale market clearing prices (Gelabert et al. (2011); Sáenz de Miera et al. (2008); Forrest and MacGill (2013); Würzburg et al. (2013); Mulder and Scholtens (2013)).

- High volatility of wind will result, with an increase of wind proportion, in more volatile day-ahead prices (Woo et al. (2011); Jacobsen and Zvingilaite (2010); Green and Vasilakos (2010)).
This difference needs a mechanism that allows to adjust positions at periods closer to delivery which is possible on the intraday market.
Uncertainty will remain a decisive part of the system and the power system offers means of flexibility to address uncertainty.

- Hydro plants have the technical capacity to provide a full start within 15 minutes.
- The value of the option to store water is high when reservoir levels are low (hydro has a marginal cost-convenience yield or opportunity cost) (Huisman et.al. (2013))
- The value of the option to store water is low when reservoir levels are high (hydro has low or zero marginal cost) (Huisman et.al. (2013))

Windpower can be balanced through flexible hydropower, however the level in hydro reservoir is important for providing price stability.
Does hydro have a stabilizing effect on the impact of wind forecasting errors on NordPool intraday prices?
**Data**

- One single market for Norway, Sweden, Finland, Denmark, Estonia and Lithuania
- 1 January 2011 through 10 November 2013
- ELBAS imbalance power prices
  - Volume weighted average price per MWh
  - Trading takes place until one hour before delivery
- Forecasted wind power
- Realized wind power
- Weekly hydro reservoir level in percentage of total reservoir capacity
- Hour 1-24, 8am-8pm peak, 8pm-8am off peak
- energienet.dk and nordpoolspot.com
The intraday price

\[ s_t = d_t + x_t \]  \hspace{1cm} (1)

Deterministic component

\[ d_t = \mu_1 + \beta \omega_t \]  \hspace{1cm} (2)

\[ \omega_t = \begin{cases} 
0 & \text{if weekdays} \\
1 & \text{if weekend} 
\end{cases} \]

- \( \mu_1 \), the mean price level in the normal state.
- \( \beta \), weekend seasonality.
MARKOV REGIME SWITCHING MODEL

- **State 1 - Normal**

  **Equation**

  Stochastic component

  \[ x_t = (1 - \alpha)x_{t-1} + \sigma_1 \epsilon_{1,t} \]  

  - \( \alpha \), the speed of mean reversion under normal market conditions.
  - \( \mu_2 \), the price increase or decrease in the non-normal state.
  - \( \sigma_1 \) and \( \sigma_2 \), volatility of the prices in the normal and non-normal state.

- **State 2 - Non-normal**

  **Equation**

  Stochastic component

  \[ x_t = \mu_2 + \sigma_2 \epsilon_{2,t} \]  

Markov regime switching model

**Equation**

Transition probability

\[ p_{i,i} = Pr\{S_t = i | S_{t-1} = i\} \] (5)

**Equation**

Wind forecast error dependent transition probability

\[ p_{i,i} = \lambda_i + \kappa_{i}^{hp}(rwnd_t - fwnd_t)l_t^h l_t^p + \kappa_{i}^{hn}(rwnd_t - fwnd_t)l_t^h l_t^n + \kappa_{i}^{lp}(rwnd_t - fwnd_t)l_t^l l_t^p + \kappa_{i}^{ln}(rwnd_t - fwnd_t)l_t^l l_t^n. \] (6)

\[ l_t^l = \text{Hydro level} < 61.4\% \text{ (average)} \]
\[ l_t^p = rwind_t > fwnd_t \text{ Excess} \]
\[ l_t^h = \text{Hydro level} \geq 61.4\% \]
\[ l_t^n = rwind_t < fwnd_t \text{ Deficit} \]

- High hydro reservoir levels: \( \kappa_i^{hp} \) and \( \kappa_i^{hn} \), effect of positive and negative forecasting errors on the transition probability during high hydro level.
- Low hydro reservoir levels: \( \kappa_i^{lp} \) and \( \kappa_i^{ln} \), effect of positive and negative forecasting errors on the transition probability during low hydro level.
Table: Parameter estimates $\mu$, $\mu_2$, $\beta$, $\alpha$, $\sigma_1$ and $\sigma_2$

<table>
<thead>
<tr>
<th></th>
<th>Off peak</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_1$</td>
<td>3.5608* (0.0217)</td>
<td>3.8637* (0.0148)</td>
</tr>
<tr>
<td>$\mu_2$</td>
<td>-0.2122* (0.0354)</td>
<td>-0.0800* (0.0227)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>-0.0166* (0.0079)</td>
<td>-0.1680* (0.0071)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.0590* (0.0039)</td>
<td>0.0585* (0.0032)</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>0.1171* (0.0014)</td>
<td>0.0841* (0.0009)</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>0.7090* (0.0172)</td>
<td>0.4786* (0.0124)</td>
</tr>
</tbody>
</table>

- $\mu_1$, which is the mean price level in the first state is higher than $\mu_2$ (negative) the mean price level in the second state.
- The volatility of the intraday price in the first state ($\sigma_1$) is lower than the volatility in the second state ($\sigma_2$).
- $\beta_1$ is negative as weekend days normally exhibit lower prices than working days and especially for the hours with higher demand.
- $\alpha$, the speed of mean reversion under normal market conditions, is equal for peak and off peak hours (0.06).
Table: Parameter estimates $\kappa_i^{hp}$, $\kappa_i^{hn}$, $\kappa_i^{lp}$ and $\kappa_i^{ln}$

<table>
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<tbody>
<tr>
<td>$\kappa_1^{hp}$</td>
<td>-0.0010* (0.0004)</td>
</tr>
<tr>
<td>$\kappa_2^{hp}$</td>
<td>0.0018* (0.0006)</td>
</tr>
<tr>
<td>$\kappa_1^{hn}$</td>
<td>0.0023* (0.0004)</td>
</tr>
<tr>
<td>$\kappa_2^{hn}$</td>
<td>0.0010 (0.0007)</td>
</tr>
<tr>
<td>$\kappa_1^{lp}$</td>
<td>0.0009 (0.0005)</td>
</tr>
<tr>
<td>$\kappa_2^{lp}$</td>
<td>-0.0003 (0.0007)</td>
</tr>
<tr>
<td>$\kappa_1^{ln}$</td>
<td>0.0001 (0.0008)</td>
</tr>
<tr>
<td>$\kappa_2^{ln}$</td>
<td>0.0020 (0.0012)</td>
</tr>
</tbody>
</table>
Effect wind forecast error on transition probability

**Figure: Off peak**

- **High Hydro**
  - **Wind Excess (pos)**
    - 1. High S/Low $\sigma$
      - Decrease
    - 2. Low S/High $\sigma$
      - Increase
  - **Wind Deficit (neg)**
    - 1. High S/Low $\sigma$
      - Increase
    - 2. Low S/High $\sigma$
      - -

- High hydro reservoir: $\kappa_{hp}^1$ is -0.0010. A positive error leads to a decrease of the probability that the prices will stay in the first state with higher prices and low volatility.

- High hydro reservoir: $\kappa_{hp}^2$ is 0.0018. A positive error leads to an increase of the probability that the prices will stay in the second state with lower prices and also diminishes the probability of switching to the first state with higher prices and low volatility.

- High hydro reservoir: $\kappa_{hn}^1$ is 0.0023. A wind deficit has a positive effect on the probability of staying in the first state with higher prices and low volatility.
Results

Table: Parameter estimates $\kappa_{i}^{hp}$, $\kappa_{i}^{hn}$, $\kappa_{i}^{lp}$ and $\kappa_{i}^{ln}$

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<td>$\kappa_{1}^{hp}$</td>
<td>0.0005 (0.0004)</td>
</tr>
<tr>
<td>$\kappa_{2}^{hp}$</td>
<td>0.0004 (0.0006)</td>
</tr>
<tr>
<td>$\kappa_{1}^{hn}$</td>
<td>0.0004 (0.0005)</td>
</tr>
<tr>
<td>$\kappa_{2}^{hn}$</td>
<td>-0.0003 (0.0006)</td>
</tr>
<tr>
<td>$\kappa_{1}^{lp}$</td>
<td>0.0013* (0.0004)</td>
</tr>
<tr>
<td>$\kappa_{2}^{lp}$</td>
<td>0.0006 (0.0006)</td>
</tr>
<tr>
<td>$\kappa_{1}^{ln}$</td>
<td>0.0008 (0.0006)</td>
</tr>
<tr>
<td>$\kappa_{2}^{ln}$</td>
<td>0.0017 (0.0017)</td>
</tr>
</tbody>
</table>
Effect wind forecast error on transition probability

Figure: Peak

Low Hydro

Wind Excess (pos)  Wind Deficit (neg)

1. High S/Low σ  2. Low S/High σ  1. High S/Low σ  2. Low S/High σ

Increase  -  -  -

Low hydro reservoir: $\kappa_{lp}^1$ is 0.0013. A positive deviation increases the probability of staying in the first state with higher prices and low volatility.
In times of higher power demand it is possible that hydropower is not the fuel determining the power price, therefore has no significant effect on the switching probabilities.

- Peak demand and low hydro reservoir level will activate fossil fuelled powerplants.
- Excess wind power supply will make conventional power plants reduce their production.
- High level in demand will not allow the prices to decline but has a positive impact on the price volatility.
To what extent does hydropower have a stabilizing effect on the impact of wind forecast errors on NordPool intraday prices.

- In general the impact of wind forecast errors on the NordPool intraday prices are stabilized by the hydro reservoir levels.
- The hydropower capacity is a significant price volatility control mechanism mainly during off-peak hours.
- During high reservoir levels wind deficits are absorbed by hydropower but wind excess is not.

Under wind forecast error, the use of hydropower capacity in intraday markets is proven to be an effective volatility control mechanism. An overall understanding of the interactions between the level in the hydro reservoirs and wind forecast errors, the expectations of ELBAS intraday prices taken into account, will result in fewer trades closer to real time lowering the balancing costs. These findings provide more insight in how electricity portfolios should be structured with respect to high and low flexibility in the power supply stack.