Exploring wind, demand and system marginal price in the single electricity market.

ESGI 102: Problem 3

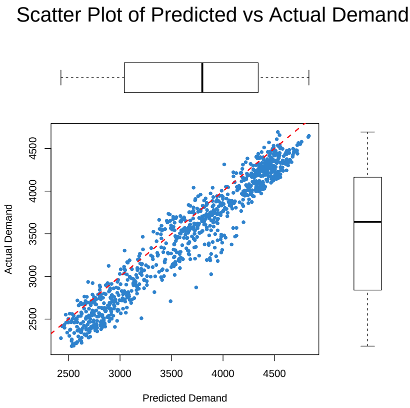
Overview

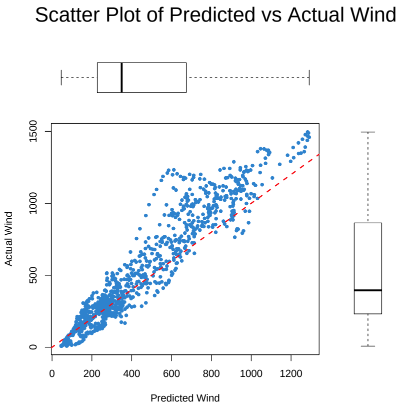
- In Ireland there is a wholesale electricity market which has been in operation since November 2007.
- This market is known as the Single Electricity Market (SEM) and incorporates all generation on the island of Ireland.
- There is a significant amount of data within the SEM.
- Currently the Market Operator (MO) publishes their expectations of **wind** and **demand** on a day ahead basis.
- They also publish their expectations as to what **prices** will outturn in the market.

Problems

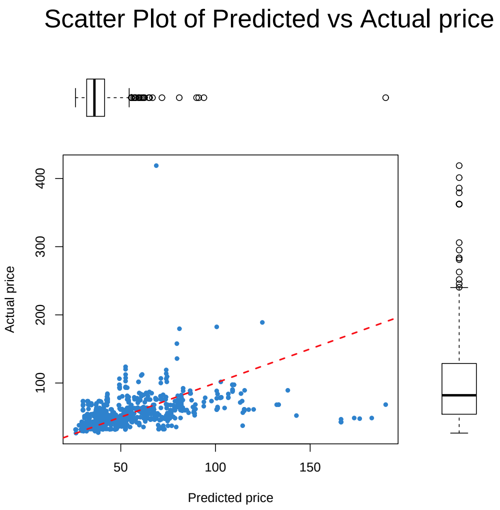
1. **Improved prediction of the SMP.**
   Given day ahead forecasts for wind, demand and price, is there a relationship between these forecasts and the actual **system marginal price** (SMP) in the market?
2. **Clustering wind forecasts.**
   Is it possible to identify a wind forecast as belonging to a particular subgrouping or cluster? For example, possible clusters could be a low forecast cluster, a high forecast cluster, and a cluster in which the wind forecast ramps up over the day. Further, if such clusters exist, is the variability between the forecast and the outturn the same or different for all the clusters?

Data: Wind & Demand





Data: System Marginal Price



Performance Metrics

We agreed on the following metrics to assess performance.

- RMSE: $\sqrt{\frac{1}{n}\sum(S_t - \hat{S}_t)^2}$
- MAE: $\frac{1}{n}\sum|S_t - \hat{S}_t|$
- MAPE: $\frac{1}{n}\sum|\frac{S_t - \hat{S}_t}{S_t}|$

S_t is the actual system marginal price at time t

$\hat{S}_t$ is the predicted system marginal price at time t

Linear Regression

Issues:

- Wind and Demand forecast not sufficient to improve upon SMP forecast, although significant effects.
- Wind and Demand not related linearly. Transformations or Generalised Linear Models needed.
- Regression errors autocorrelated.

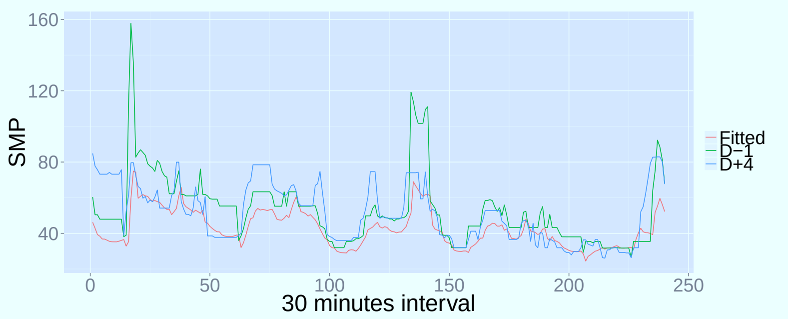
Regression model:

$$\log S_t^{+4} = \beta_1 W_t^{-1} + \beta_2 D_t^{-1} + \beta_3 \log S_t^{-1} + \sum_{i=48}^{53} \phi_i \mathrm{B}^i \log S_t^{+4} + \gamma \mathrm{Hour} + \delta \mathrm{Weekday} + \varepsilon$$

Results

In sample: $R^2 = 0.56$ (31004 observations)
Out of sample: May 2014 (4-day ahead recursive forecasts)

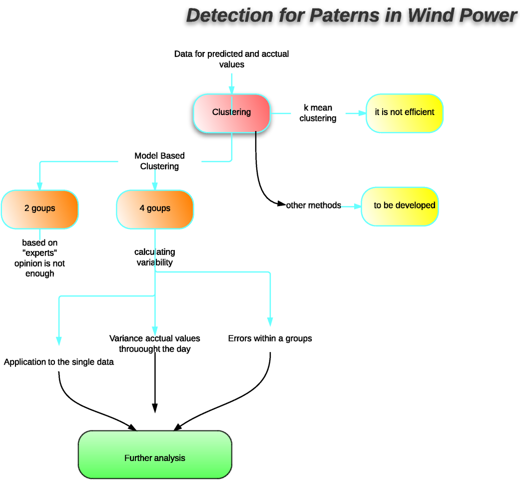
	RMSE	MAPE	MAE
SMP D-1	25.3	0.217	12.1
LM	22.4	0.198	12.2



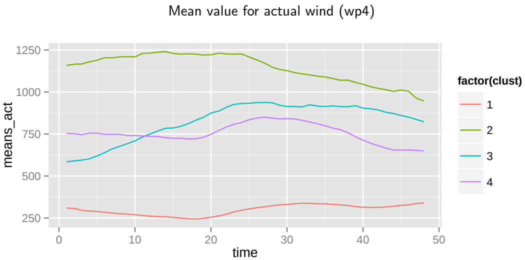
Regression Conclusions

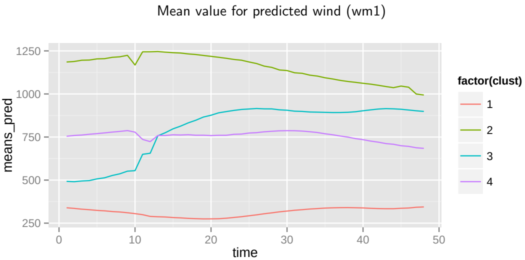
- The autocorrelation of errors has not been succesfully confronted by time-series analysis. More data on outlier observations (spikes) needed.
- The effect of wind is statistically significant, however intra-day wind patterns have not been explored in the regression setting.
- Given accurate predictions for the SMP D+4 price, one could start exploring any patterns in the error of these predictions with wind.

Clustering: Concept map

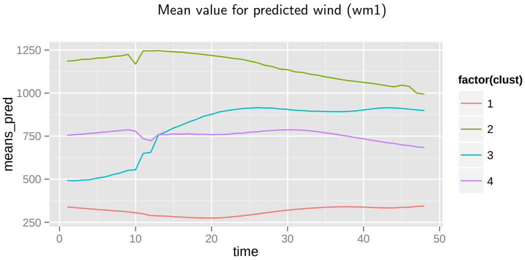


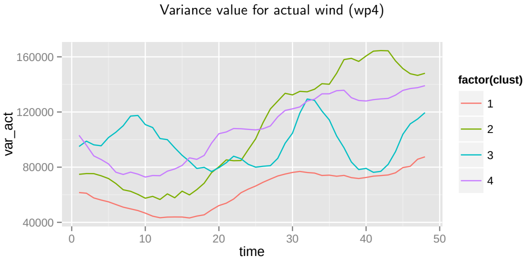
Mean value for actual and predicted wind





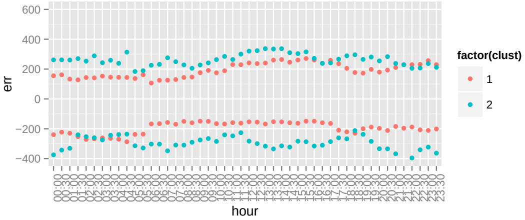
Mean value for predicted wind and variance for actual wind



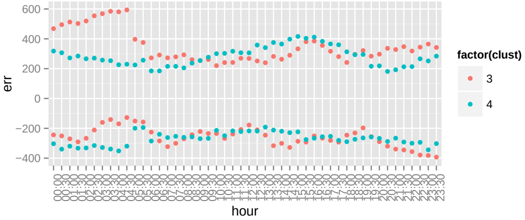


Intervals of errors for different groups

Intervals of errors for 2 groups



Intervals of errors for next 2 groups



Error intervals applied to predicted data

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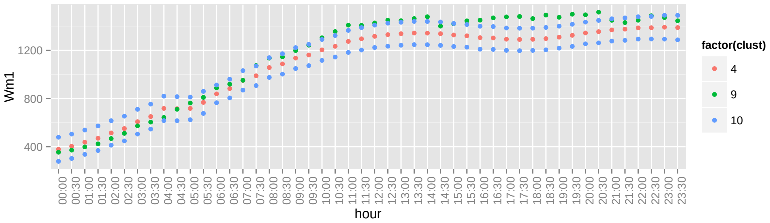

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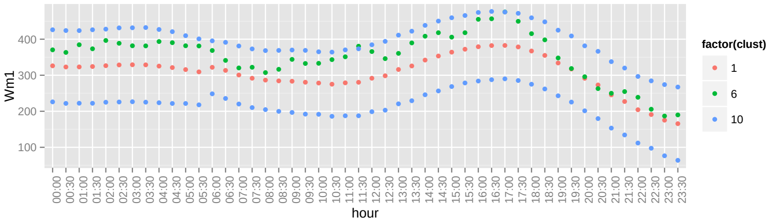

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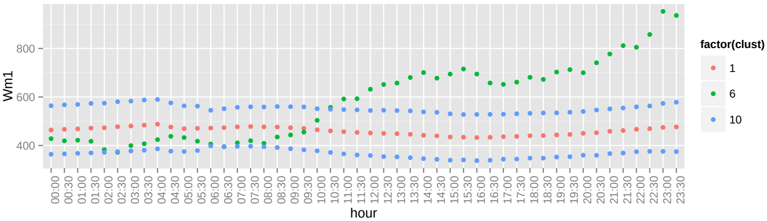

Proxy Day Method

- A Proxy Day approach attempts to select a baseline day that most accurately matches the wind forecast and forecast electricity demand to the current day for forecasting the System Marginal Price, SMP.
  - **Stage 1: Find Correlated Days**
  - **Stage 2: Probability Estimation of the Decision Making Process based on Historical Electrical Generator Market Schedule**

$$X = P_1 Q_1 + P_2 Q_2 + P_3 Q_3 + ... + P_n Q_n + \text{No Load Cost}$$

Start Up Cost

  - **Stage 3: Calculation of the 'Sparks Margin' as an expected cost based on generator operating costs.**
  - **Stage 4: Updating the System Marginal Price**

$$\text{System Marginal Price} = (69.95 \times \text{Gas Price})/Fx + 0.377 \times \text{Carbon Price} + \text{Spark}$$

The current market estimation of the gas price and carbon price can be input into this model. The spark can be estimated from the proxy day model.

Differential equation method

- Preliminary considerations:
  1. We can not expect a linear dependence of SMP^{+4} on W, D and SMP^{-1}.
  2. A result based on the forecast SMP^{-1} might amplify the inital error.
- Find a function for the price $P(W, D, G, C, t)$ being a better forecast than SMP^{-1} by
  1. an extrapolation,
  2. a differential equation.

Initial value problem

- The differential equation is given by

$$\begin{cases} P_W + P_G + P_C + P_D + P_t = f(W, G, C, D, t), \\ P(W_0, G_0, C_0, D_0, t_0) = SMP^{+4}(W_0, C_0, D_0, t_0), \end{cases}$$

$$(W, G, C, D, t) \in Q \times [t_0, t + 1d]$$

  The function f is a smooth approximation of the total variation $\tilde{f}$ of the actual price SMP^{+4}.

- For the last four days not covered by SMP^{+4} use a loose function $\widetilde{SMP}^{+4}$ provided by the company.

Approximation function

The discrete function $\tilde{f}$ is

$$
\begin{aligned}
&\widetilde{f}(W, G, C, D, t) = \\
&\quad \frac{\widetilde{SMP^4}\left(W + \Delta W, G + \Delta G, C + \Delta C, D + \Delta D, t + \Delta t\right) - \widetilde{SMP^4}\left(W, G + \Delta G, C + \Delta C, D + \Delta D, t + \Delta t\right)}{\Delta W} \\
&\quad + \frac{\widetilde{SMP^4}\left(W, G + \Delta G, C + \Delta C, D + \Delta D, t + \Delta t\right) - \widetilde{SMP^4}\left(W, G, C + \Delta C, D + \Delta D, t + \Delta t\right)}{\Delta G} \\
&\quad + \frac{\widetilde{SMP^4}\left(W, G, C + \Delta C, D + \Delta D, t + \Delta t\right) - \widetilde{SMP^4}\left(W, G, C, D + \Delta D, t + \Delta t\right)}{\Delta C} \\
&\quad + \frac{\widetilde{SMP^4}\left(W, G, C, D + \Delta D, t + \Delta t\right) - \widetilde{SMP^4}\left(W, G, C, D, t + \Delta t\right)}{\Delta D} \\
&\quad + \frac{\widetilde{SMP^4}\left(W, G, C, D, t + \Delta t\right) - \widetilde{SMP^4}\left(W, G, C, D, t\right)}{\Delta t}.
\end{aligned}
$$

Summary

1. $$SMP^4 \longrightarrow \widetilde{SMP^4}$$

2. $$\widetilde{f} = TotalVariation\left(\widetilde{SMP^4}\right)$$

3. $$f = Smooth(\widetilde{f})$$

4. $$P_W + P_G + P_C + P_D + P_t = f(W, G, C, D, t)$$

Conclusions

- It is known that there exists a unique solution for this IVP.
- The solution can be explicitly calculated by using math software, e. g. Matlab.
- This approach allows to answer both problems.

Project Conclusions

- Some progress has been made in assisting predict the system marginal price (SMP).
- Models still fail to capture spiking in prices, but extra data is being made available: Gas Price, Carbon Price.
- Developed models improve on current market predictions.