Arbitrage Strategy of the spread between the Day-Ahead and Real Time prices of delivery of electricity

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Bidding problem

Financial actor aiming to bid on electrical market. At day j, decision to bid on hour h at day $j+1$.

Short position sell electricity at price $d^*_{j+1,h}$ (per MW)

Long position buy electricity at price $d^*_{j+1,h}$

Based on the biddings, a day-ahead (DA) price is determined at day j (but after the decision of $d^*_{j+1,h}$). The contract is selected if

$$\begin{aligned} d^*_{j+1,h} &< d_{j+1,h} \quad \text{(short)} \\ d^*_{j+1,h} &> d_{j+1,h} \quad \text{(long)} \end{aligned}$$

But the electricity cannot be stored ! The actor will immediately

Short position buy electricity at price $r_{j+1,h}$

Long position sell electricity at price $r_{j+1,h}$

where $r_{j+1,h}$ is the real-time electricity price in the market at hour h, day $j+1$.

Payoff

Assume that we trade $q_{j+1,h}$ MW. Payoff :

- Short position

$$q_{j+1,h}(d^*_{j+1,h} - r_{j+1,h})\,\mathbb{1}_{d^*_{j+1,h} < d_{j+1,h}}$$

- Long position

$$q_{j+1,h}(r_{j+1,h} - d^*_{j+1,h})\,\mathbb{1}_{d^*_{j+1,h} > d_{j+1,h}}$$

But $r_{j+1,h}$ is unknown when fixing $d^*_{j+1,h}$! Spread :

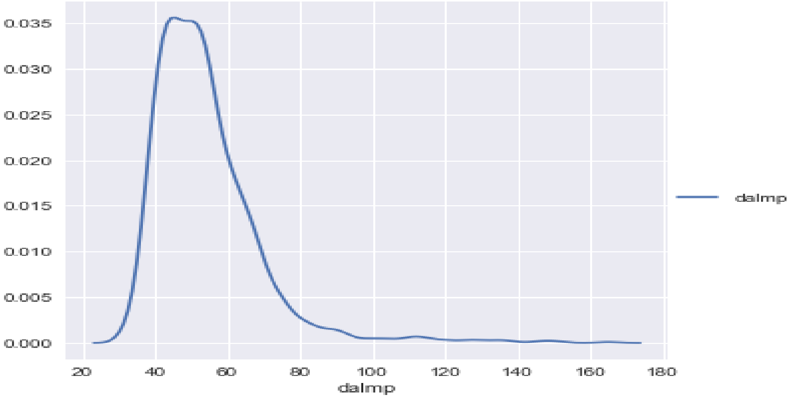
$$s_{j+1,h} := d_{j+1,h} - r_{j+1,h}$$

$d_{j+1,h}$ and $r_{j+1,h}$ are unknown at the bidding time.

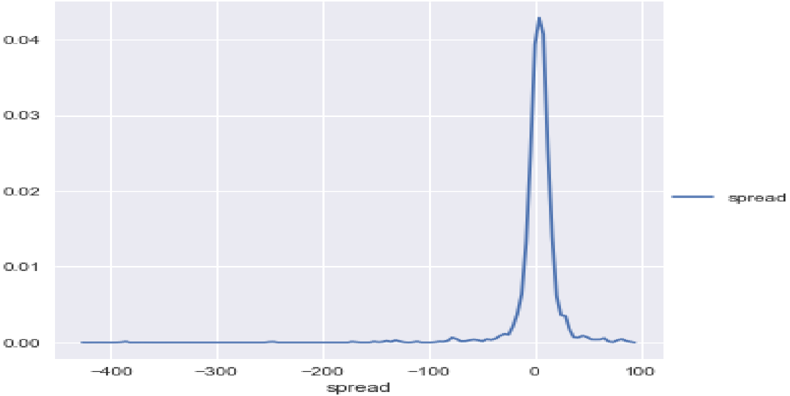
Risk !

(Source : CNN, 2011)

Day ahead price density

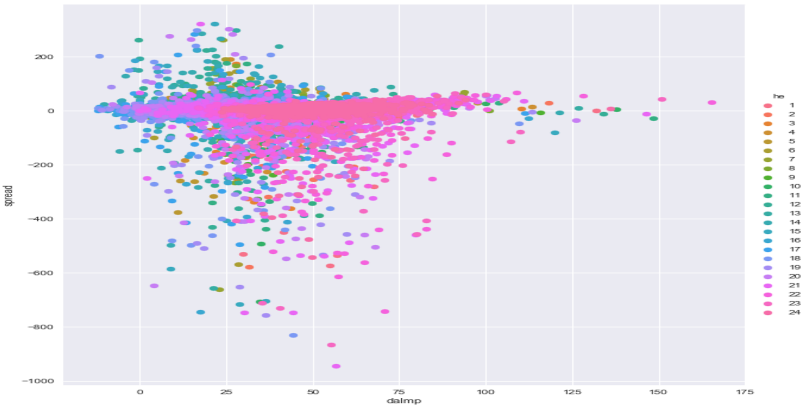


Spread density



DA – annual spread

Hourly day ahead price vs spread.



Highly random but highly dependent !

Spread skewness

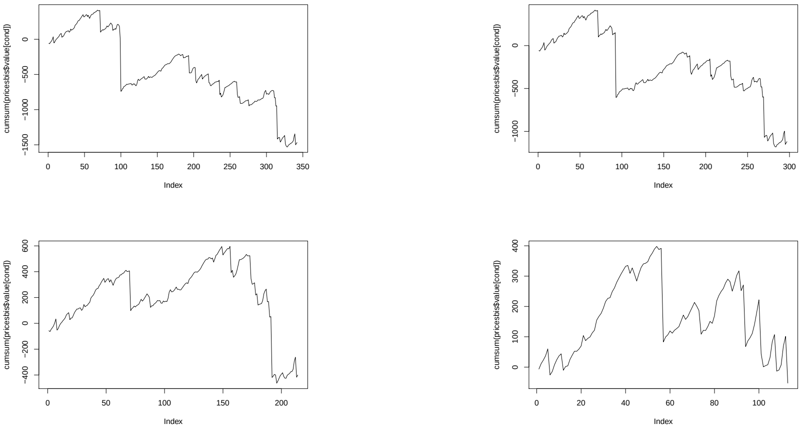
The algorithm must decide every day for the next day which hours to be short or long and at which price Recall that

$$s_{j+1,h} := d_{j+1,h} - r_{j+1,h}$$

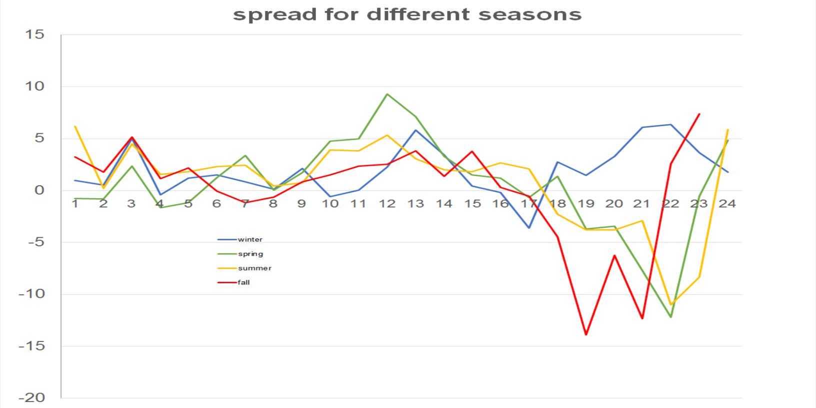
- $E[s_{j+1,h}] \approx \$3$.
- But heavy left tail ; the spread realization can be very negative. Upper real price in California : \$1000. So the spread can be close to -\$1000.
  - Problem in short position
  - Advantage in long position

Naive short strategies for the summer

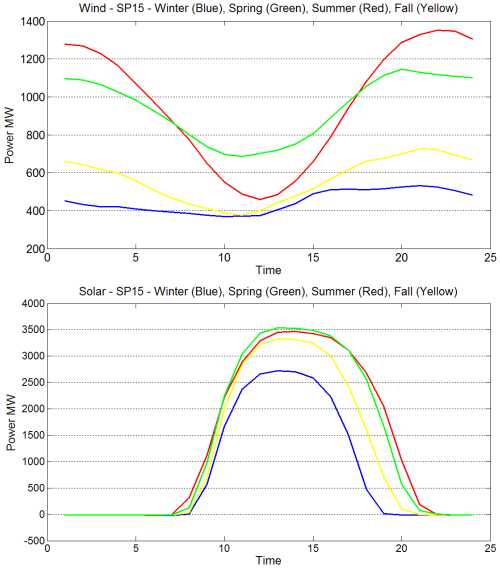
Cumulative profit over summers 2014–2017 of a short position 1MW at hour 19. Top left : price taker strategy. Top right : short at 30$. Bottom left : short at 40$. Bottom right : short at 50$.



Seasonality effects



Wind and solar seasonality



Fundamental variables

$$
\begin{aligned}
l_{j,h} &= \text{actual load of day } j \text{ hour } h \\
d_{j,h} &= \text{day-ahead prices of day } j \text{ hour } h \\
r_{j,h} &= \text{real time prices of day } j \text{ hour } h \\
l_{j,h,1} &= \text{1-DA forecast loads of day } j \text{ hour } h \\
l_{j,h,2} &= \text{2-DA forecast loads of day } j \text{ hour } h \\
w_{j,h} &= \text{actual wind of day } j \text{ hour } h \\
w_{j,h,1} &= \text{DA forecast wind of day } j \text{ hour } h \\
s_{j,h} &= \text{actual solar of day } j \text{ hour } h \\
s_{j,h,1} &= \text{DA forecast solar of day } j \text{ hour } h \\
o_{j,h} &= \text{actual outage of day } j \text{ hour } h \\
o_{j,h,1} &= \text{DA forecast outage of day } j \text{ hour } h
\end{aligned}
$$

Fundamental variables (cont'd)

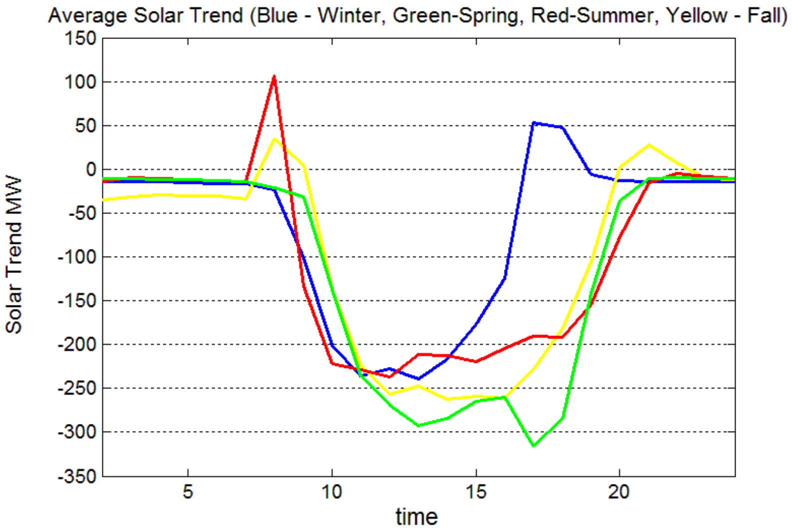
We can also examine their evolutions

$$
\begin{aligned}
e^l_{j-1} &= l_{j-2,h} - l_{j-2,h,1} \\
e^w_{j-1} &= w_{j-2,h} - w_{j-2,h,1} \\
e^s_{j-1} &= s_{j-2,h} - s_{j-2,h,1} \\
\varepsilon^l_j &= l_{j,h,1} - l_{j-2,h} \\
\varepsilon^w_j &= w_{j,h,1} - l_{j-2,h} \\
e^l_j &= l_{j,h,2} - l_{j-2,h}
\end{aligned}
$$

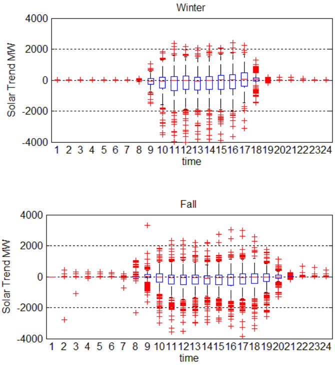
Can we rely on these quantities ?

Forecasted increase of solar

Two-day ahead forecast error



Forecast increase of solar (cont'd)



Clustering

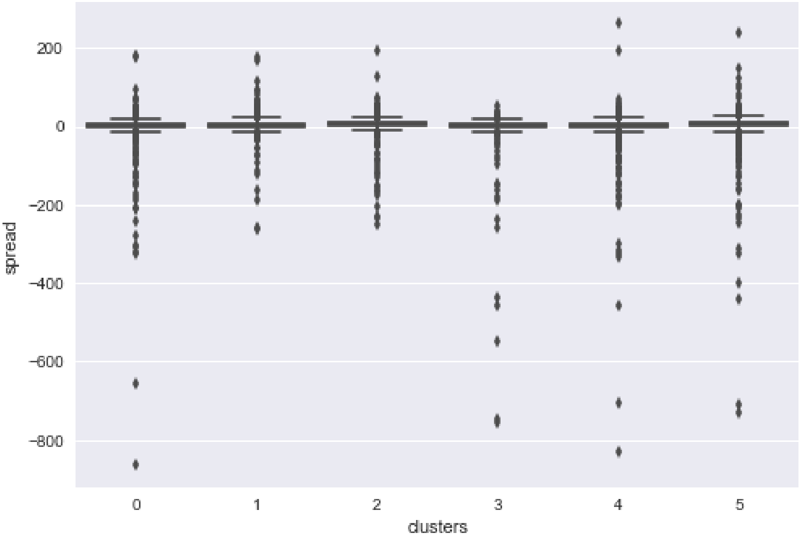
Main hope : try to reduce random noise by clustering similar observations.

Preliminary results using k-means, 6 clusters, based on the fundamental variables.

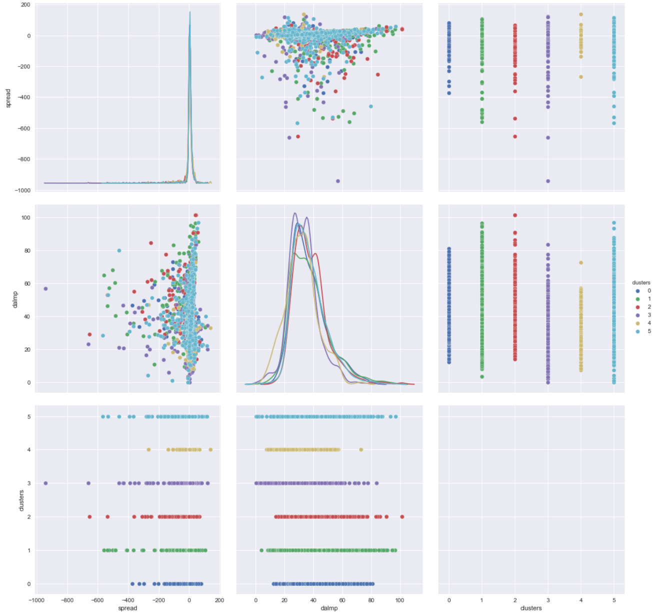
Main hope : develop the ability to better predict the spread distribution and isolate the spikes.

- positive spread and no spike : short strategy !
- negative spread : long strategy !

Illustration : summer clustering



Scatter plot for summer



Bidding optimization problem

Goal : maximize the hourly profit.

$$
\begin{aligned}
\max_{d^*_{j+1,h}, q_{j+1,h}, y_s, y_l} \quad & E[y_s(q_{j+1,h}(d^*_{j+1,h} - r_{j+1,h})\,\mathbb{1}_{d^*_{j+1,h} < d_{j+1,h}}) + \\
& \quad y_l(q_{j+1,h}(r_{j+1,h} - d^*_{j+1,h})\,\mathbb{1}_{d^*_{j+1,h} > d_{j+1,h}})] \\
\text{s.t.} \quad & y_s, y_l \in \{0,1\} \\
& \text{risk aversion}
\end{aligned}
$$

The risk aversion could be

$$E[\text{loss} \mid \text{loss} > \kappa] \leq \lambda.$$

Stochastic program. Suggestion : solve it using a sample average approximation. Still to investigate !

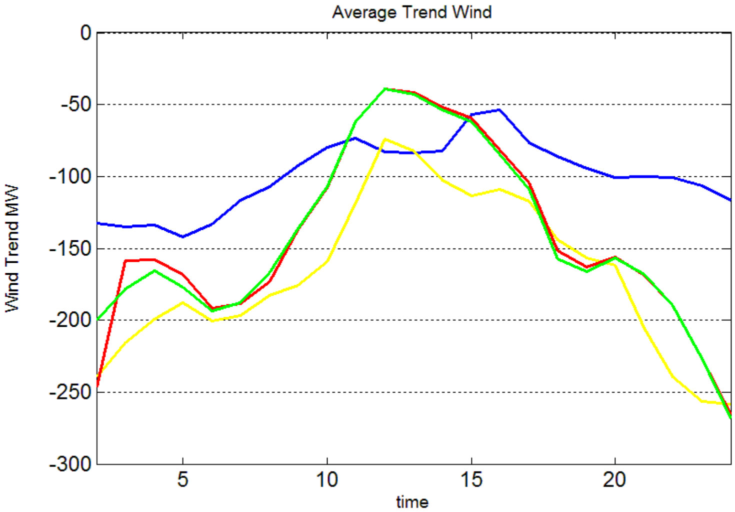
Future Work

Encouraging observations, but still a lot of work to do

- Clustering : investigate the choice of variables, and alternative clustering approaches
- Translate each cluster in a policy decision
    1. qualitative approach, and human decision
    2. automatize the bidding strategy using stochastic programming
- Validate the proposed methods (back-testing on historical data, out-of-sample validation)

Forecasted increase of wind

Two-day ahead forecast error



Forecast increase of solar (cont'd)