Arbitrage in short-term electricity markets: what we can gain from multidimensional probabilistic forecasts.

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A small RES producer's trading

- A wind farm with a representative market share
- Intermittent generation
- Sells energy at market **clearing prices**
- Bids an amount of energy to **day-ahead** market for every hour in the next day
- Needs to settle the balance in the **intraday** market

Goal of the forecast

$\hat{W}$
forecast
of wind
generation

day-ahead → $q\hat{W}$

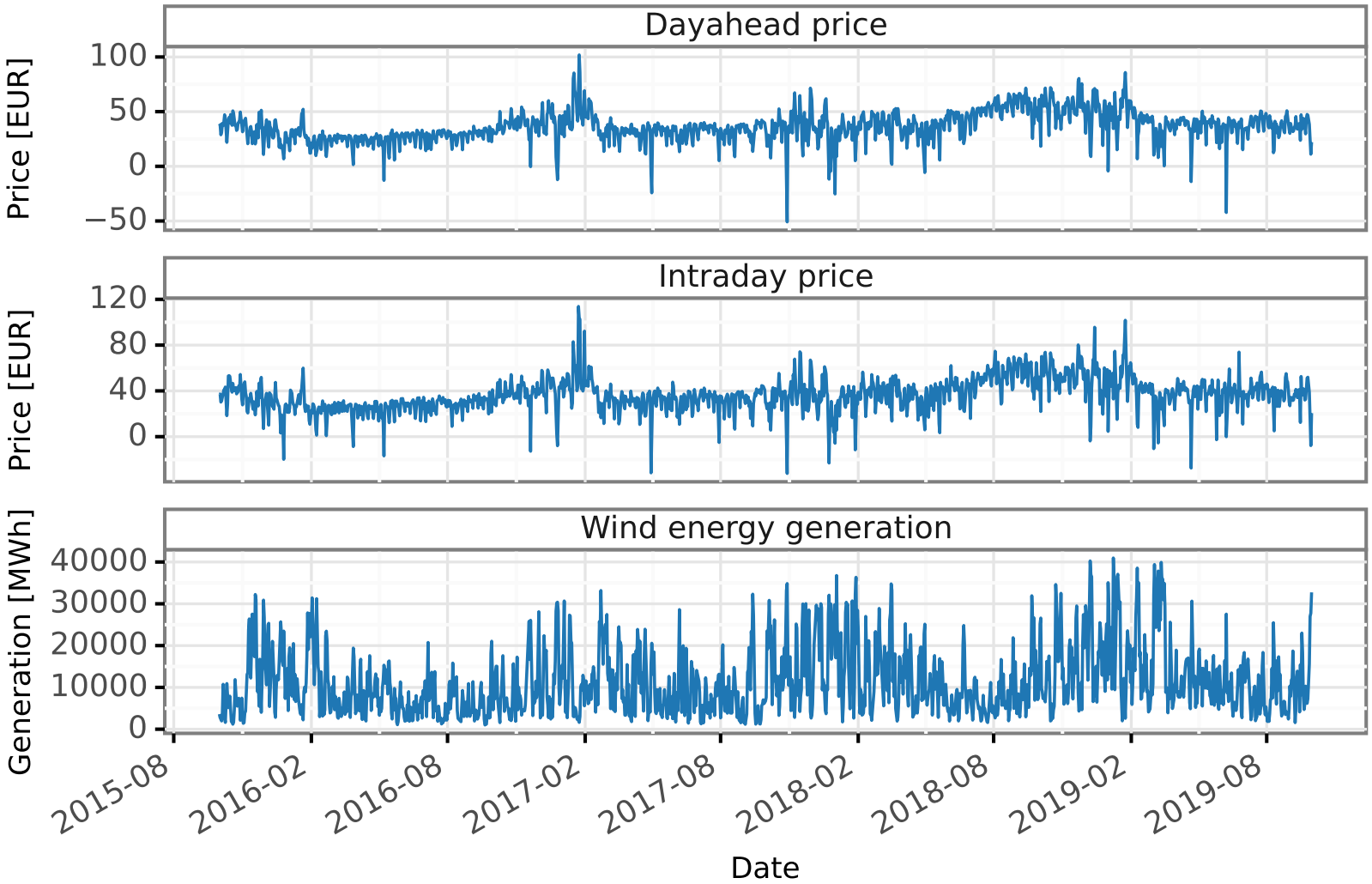
intraday → $W - q\hat{W}$

Profit of a generator

$$\Pi(q) = \underbrace{q\hat{W}_{t,h}DA_{t,h}}_{\text{DA income}} + \underbrace{(W_{t,h} - q\hat{W}_{t,h})ID_{t,h}}_{\text{ID income}} - \underbrace{W_{t,h}C_{O\&M}}_{\text{O\&M costs}}.$$

- $DA_{t,h}$, $ID_{t,h}$ – day-ahead and intraday prices
- $C_{O\&M}$ – operational and maintenance costs, incl. trading fees
- $\hat{W}_{d,h}$, $W_{d,h}$ – forecasted and actual wind energy generation

Data – EPEX SPOT



The predictive model (ARX model) for prices

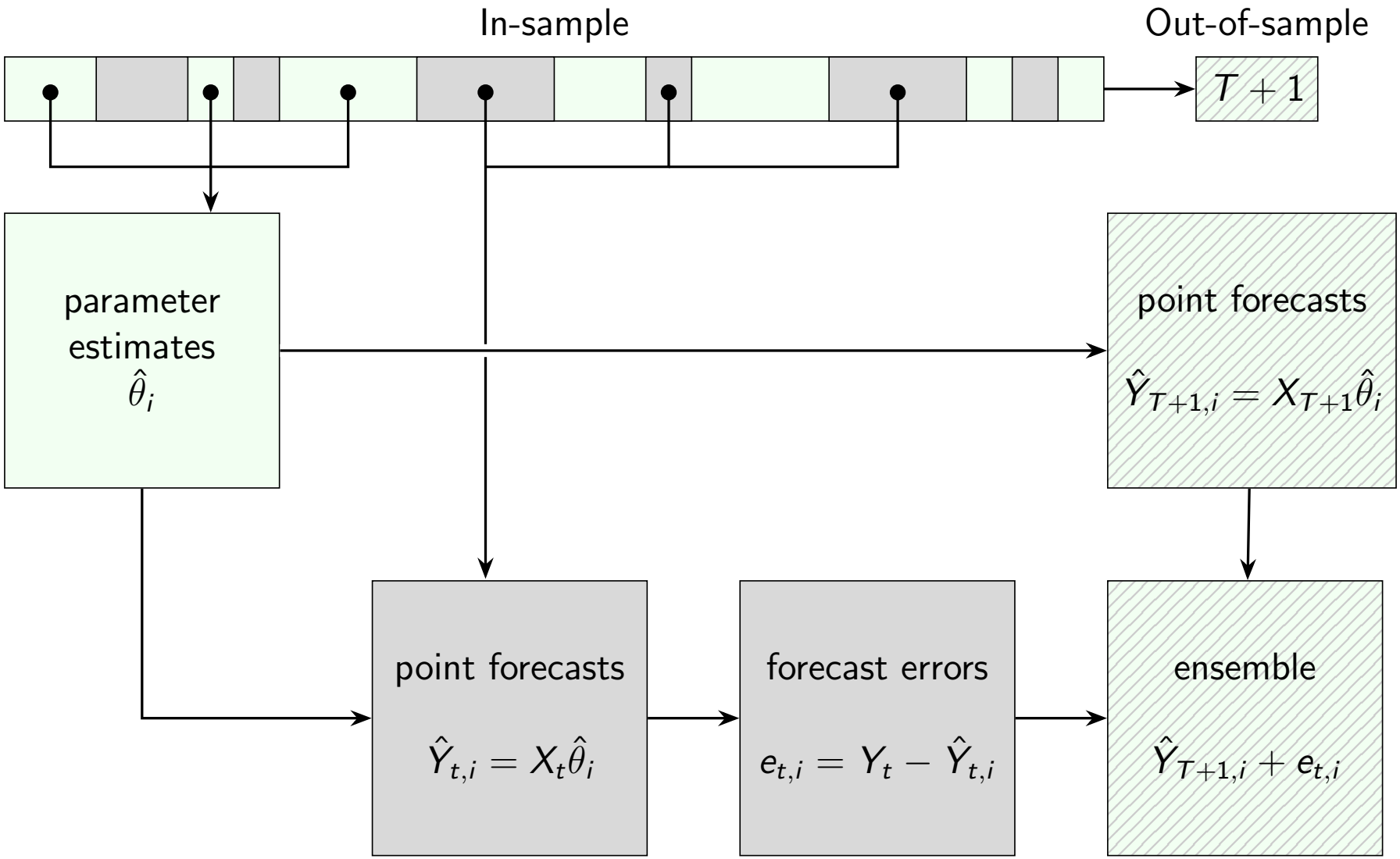
$$DA_{t,h} = \underbrace{\sum_{p\in\{1,\dots,7\}} \theta_{h,p} DA_{t-p,h}}_{\text{AR component}} + \underbrace{\beta_{h,1} DA_{t-1,ave} + \beta_{h,24} DA_{t-1,min} + \beta_{h,3} DA_{t-1,max}}_{\text{Daily quantities}} +$$
$$\underbrace{\beta^L_{h,4} FL_{t,h} + \beta^L_{h,5} FR_{t,h}}_{\text{Forecasts of fundamentals}} + \underbrace{\beta^L_{h,6} C_{t-1,h} + \beta^L_{h,7} G_{t-1,h}}_{\text{Fuel prices}} + \alpha_h D_t + \varepsilon_{t,h}$$

$$ID_{t,h} = \alpha_h D_t + \theta_{h,1} ID^*_{t-1,h} + \underbrace{\sum_{p\in\{2,\dots,7\}} \theta_{h,p} ID_{t-p,h}}_{\text{AR component}} + \underbrace{\beta^L_{h,6} C_{t-1,h} + \beta^L_{h,7} G_{t-1,h}}_{\text{Fuel prices}} +$$
$$\underbrace{\beta_{h,1} DA_{t-1,ave} + \beta_{h,2} DA_{t-1,min} + \beta_{h,3} DA_{t-1,max}}_{\text{Daily day-ahead quantities}} + \underbrace{\beta^L_{h,4} FL_{t,h} + \beta^L_{h,5} FR_{t,h}}_{\text{Forecasts of fundamentals}} + \varepsilon_{t,h}$$

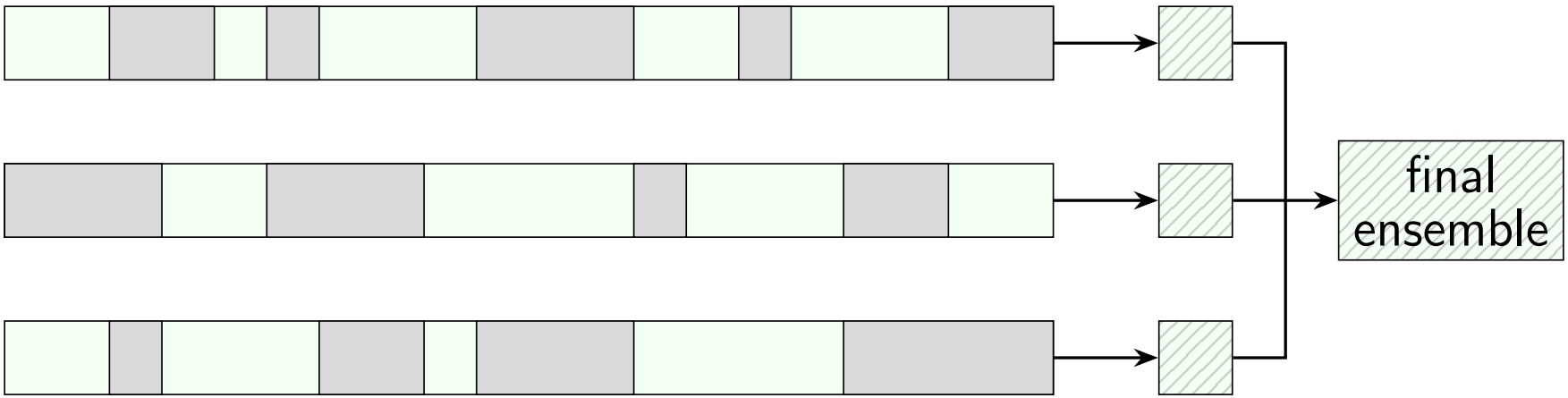
The predictive model for wind

$$W_{d,h} = \underbrace{\alpha_h^W D_d^W}_{\text{Constant}} + \underbrace{\theta_h^W W_{d-1,h}^*}_{\text{AR component}} + \underbrace{\beta_{h,1}^W FW_{d,h} + \beta_{h,2}^W FW_{d,h-1} + \beta_{h,3}^W FW_{d,h+1}}_{\text{TSO forecasts}} + \varepsilon_{d,h}^W$$

Multiple split: from ARX to probabilistic forecasts



Multiple split: repeating training/validation splits



Statistical evaluation of multiple split method

1. Variables:
   - **electricity prices**: day-ahead and intraday
   - **fundamentals**: load, wind, RES generation
   - **linear combinations**: price spread, residual load
2. Accuracy measures:
   - prediction interval coverage probability (PICP)
   - Kupiec test
   - continuous ranked probability score (CRPS)
   - reliability index (one- and multidimensional)

Summary of statistical performance

- Compared models:
  - historical simulation
  - quantile regression (QR)
  - multiple split with 1 and 20 splits (MS)
- Best PICP: **historical simulation** and **MS(20)**
- Best Kupiec test results: **MS(20)**
- Best CRPS: **quantile regression**
- Best reliability index: **MS(20)**

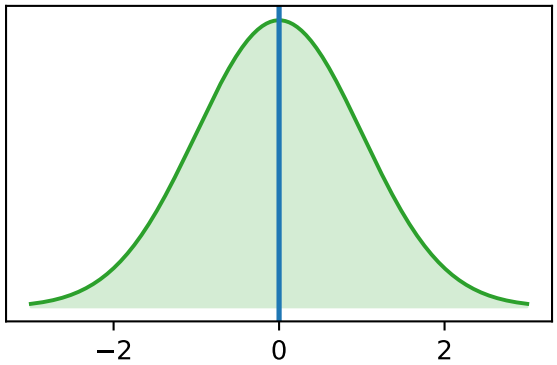
Market strategy: decisions made by the generator

1. Forecasting values of prices and wind generation
2. Choosing the optimal proportion q of generation $\hat{W}$ sold in day-ahead market:
   - forecasting profit distribution
   - choosing the objective function
   - selecting q to maximize objective function
3. Stopping trading for certain hours (curtailment)

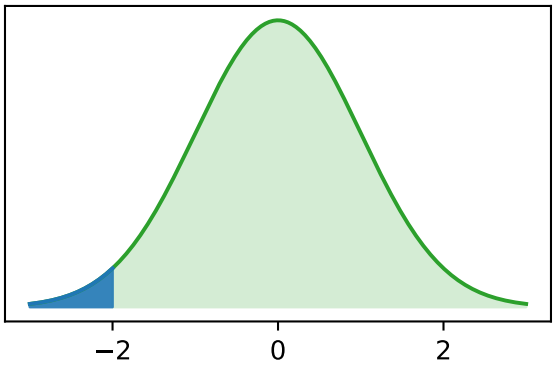
Selection of optimal q: loss functions

For each computed ensemble of possible profits, choose q to:

Maximize median profit



Maximize $VaR_{0.05}$



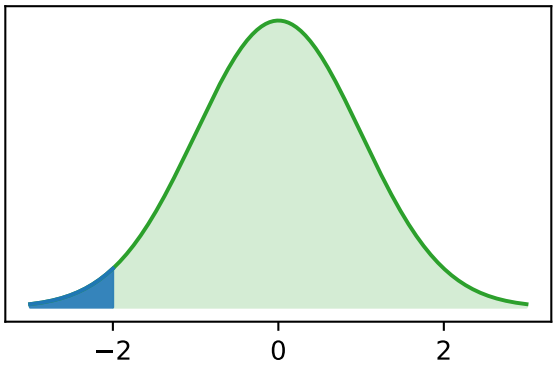
Maximize Sharpe ratio

$$SR = \frac{\bar{\Pi}}{\sigma_{\Pi}}$$

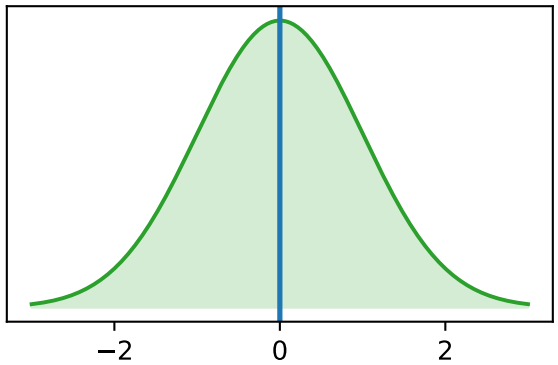
Stopping trading: choosing the cutoff quantile

We aim to avoid losses.

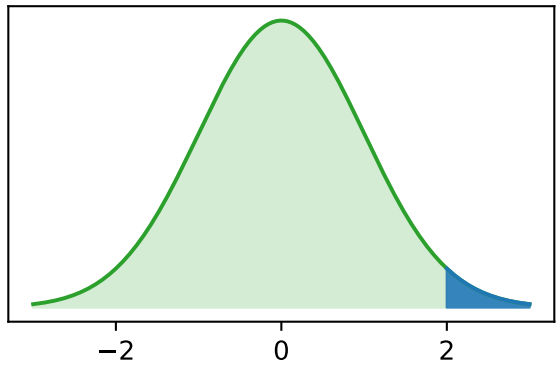
What is our risk appetite?



risk averse



risk neutral

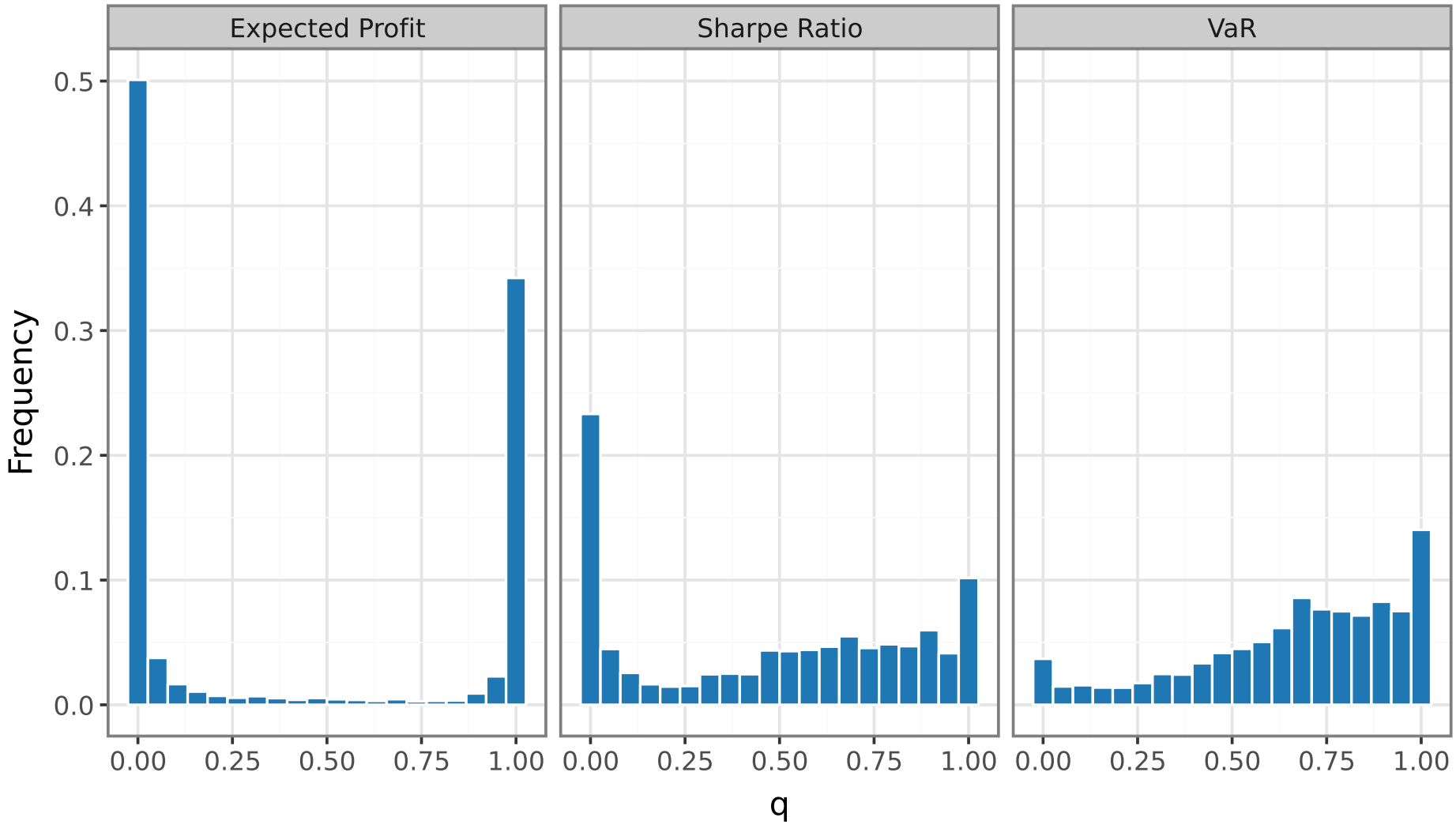


risk seeking

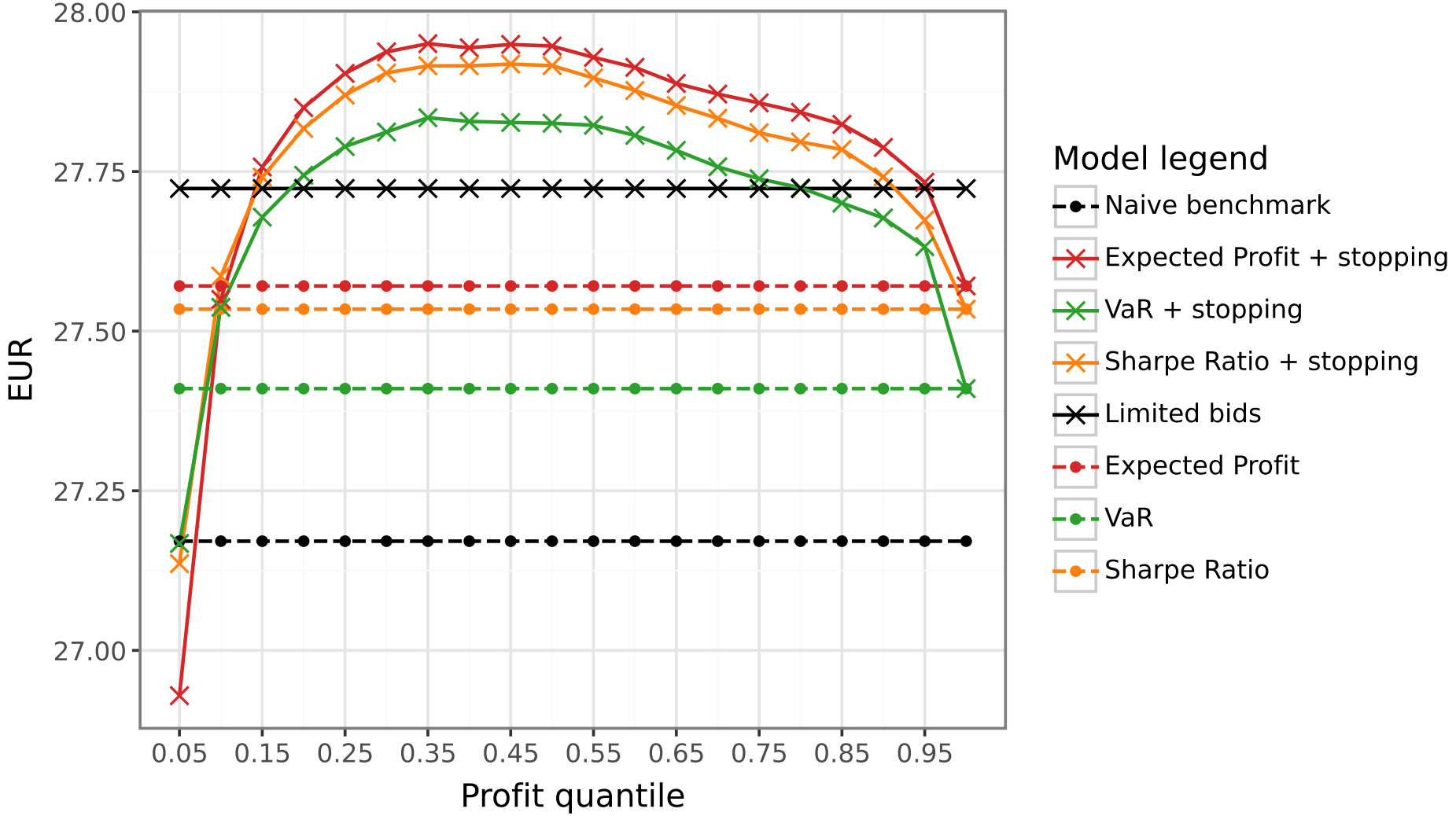
Benchmark approaches

- Naive: $\hat{W}$ always sold in day-ahead market ($q = 1$)
- Limited bids: $\hat{W}$ sold in day-ahead market ($q = 1$) when $DA > 0$

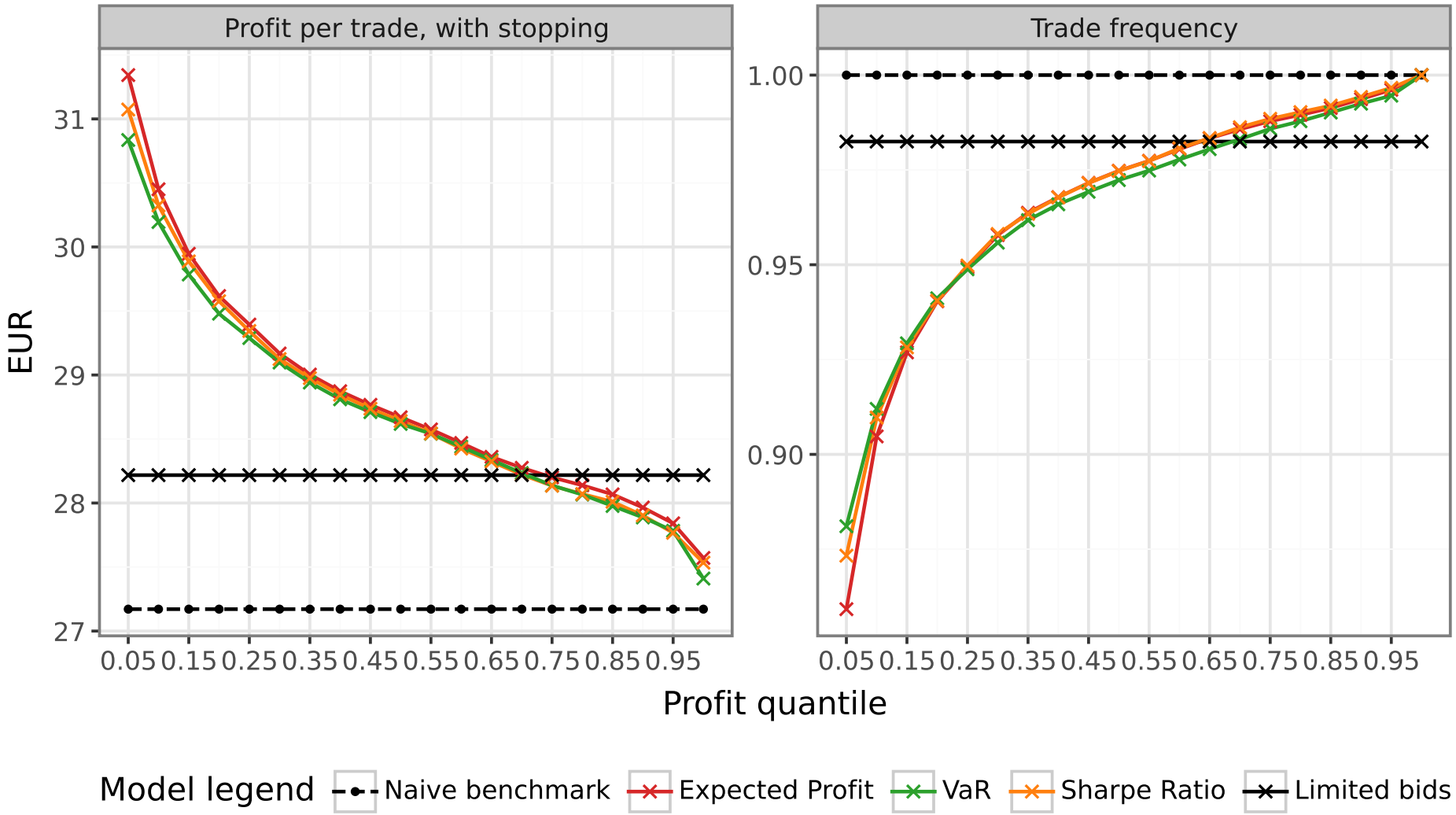
Results – histograms of selected values of q



Results – total profit



Results – profit per trade



Conclusions

- Multiple split allows direct **joint probabilistic forecasting** of prices and fundamentals
- It can be used with most point forecasting models
- Thus, it is possible to build **market strategy** with market selection and stopping rules
- Knowing when **not to trade** is the most important
- **Moderate risk aversion** allows to maximize profits

More details

https://arxiv.org/abs/2407.07795
Maciejowska, K., Nitka, W., 2024. Multiple split approach – multidimensional probabilistic forecasting of electricity markets. Working paper.