Dynamic Hedging of Futures Term Structure Risk for Renewable Power Producers

Prof. Dr. Nils Löhndorf
Motivation

- Large consumers / producers of energy commodities hedge energy prices using energy derivatives
- Contracts can be over-the-counter (OTC) or exchange traded
- Energy exchanges (EEX, TTF, Nasdaq) offer standardized products like futures and options
- Movements of the term structure as well as production volumes are uncertain
What is the problem?

- Futures contracts are the most important hedging instruments
- Finding the optimal mix, timing and volumes is difficult
- Companies calibrate hedge plans using rules-of-thumb
- Energy traders speculate on the right moment when to buy or sell
- Renewable producers face the risk of over-hedging
- Model-driven approaches are lacking
The Hedging Decision Process

- Production Forecast
- Risk Management

Hedge Target/Ratio → Trading → Cash Flow

Market Information:
- Available contracts
- Market liquidity
- Term structure volatility
How does a hedge plan look like?
Example: Hydropower producer with 2500 MW capacity
Hedging Decision Process with a Model

WITHOUT MODEL

Production Forecast

Risk Management

Hedge Target/Ratio

Trading

Cash Flows

WITH MODEL

Production Forecast

Risk Measure

MODEL

Historical Data

Trading

Cash Flows

Simulated Cash Flows

Quantitative / Price Targets
Contract Trading and Delivery Periods

March Contract
- Planning starts on March 10
- No trading on Easter
- No trading on weekends

Q2 Contract
- Cascading of quarterly and annual contracts

April Contract

May Contract

June Contract
- No trading on Easter
- No trading on weekends

Trading Days
Delivery Period
Term Structure Dynamics
Example: EEX German Base Futures (Fair Value)

Source: Refinitiv EIKON, TRDEBFVDc*
<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th>Risk factors</th>
<th>Liquidity cost</th>
<th>Risk measure</th>
<th>Contracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimoski &amp; al (2018)</td>
<td>48 semi-month</td>
<td>PFC, volume</td>
<td>No</td>
<td>Nested CVaR</td>
<td>M,Q,Y</td>
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<tr>
<td>Gauthier &amp; al (2016)</td>
<td>4 weeks</td>
<td>PFC, volume</td>
<td>Yes</td>
<td>Static, Variance</td>
<td>W</td>
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<tr>
<td>Kettunen &amp; el. (2009)</td>
<td>6 weeks</td>
<td>PFC, volume</td>
<td>No</td>
<td>Terminal CVaR</td>
<td>W,M</td>
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<tr>
<td>Mo &amp; al (2001)</td>
<td>52 weeks</td>
<td>Spot, volume</td>
<td>No</td>
<td>Cost constraint</td>
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<tr>
<td>Secomandi &amp; Bo (2021)</td>
<td>24 months</td>
<td>PFC</td>
<td>No</td>
<td>Static, Variance</td>
<td>M</td>
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<tr>
<td>THIS WORK</td>
<td>&gt;730 days</td>
<td>PFC, volume</td>
<td>Yes</td>
<td>Nested CVaR</td>
<td>W,M,Q,Y</td>
</tr>
</tbody>
</table>
Measuring Market Impact Cost
Example: Sept-22 Future Nordic

Snapshot of the order book
- ask
- bid

Source: NASDAQ OMX
Detailed Model of Trading Process

- Production Forecast
- Risk Management

- Hedge Target/Ratio
- Trading
- Cash Flow

MODEL

- Liquidity Model
- PFC Dynamics
- Volumetric Uncertainty

- Trading Decisions
- Stochastic Process

SOLVER

- Risk Measure

Simulated Cash Flows
Multistage Stochastic Programming

\[
\min_{A_1 x_1=b_1, \; x_1 \geq 0} \; c_1' x_1 + \mathbb{E}_{\xi_1} \left[ \min_{A_2 x_2+B_2 x_1=b_2, \; x_2 \geq 0} \; c_2' x_2 + \cdots + \mathbb{E}_{\xi_{[T-1]}} \left[ \min_{A_T x_T+B_T x_{T-1}=b_T, \; x_T \geq 0} \; c_T' x_T \right] \right]
\]

- \( \xi_{[t]} = (\xi_1, \ldots, \xi_t) \): history of stochastic data process up to time \( t \)
- \( \xi_t = (c_t, A_t, B_t, b_t) \): random model parameters (e.g., prices, volumes)
- \( \mathbb{E}_{\xi_{[t-1]}} \): expectation conditional on history of data process
Dynamic Programming Reformulation

\[
\begin{aligned}
\min_{\substack{A_1 x_1 = b_1 \\ x_1 \geq 0}} & \quad c'_1 x_1 + \mathbb{E}_{\xi_1} \left[ \min_{\substack{A_2 x_2 + B_2 x_1 = b_2 \\ x_2 \geq 0}} c'_2 x_2 + \cdots + \mathbb{E}_{\xi_{T-1}} \left[ \min_{\substack{A_T x_T + B_T x_{T-1} = b_T \\ x_T \geq 0}} c'_T x_T \right] \right] \\
\end{aligned}
\]

- Assume Markovian data process: \( P(\xi_t) = P(\xi_{[t]}) \)
- \( Q_t \): value function of dynamic program

\[
Q_t(x_{t-1}, \xi_t) = \min_{\substack{A_t x_t + B_t x_{t-1} = b_t \\ x_t \geq 0}} c'_t x_t + \mathbb{E}_{\xi_t} [Q_t(x_t, \xi_{t+1})]
\]
Stochastic-Dynamic Programming

\[ Q_t(x_{t-1}, \xi_t) = \min_{A_t x_t + B_t x_{t-1} = b_t} c'_t x_t + \sum_{\xi_{t+1} \in \mathcal{N}(\xi_1, \ldots, \xi_t)} P(\xi_{t+1} | \xi_t) Q_t(x_t, \xi_{t+1}) \]

- \( P(\xi | \xi_t) \): Transition probability matrix
- \( Q_t \): Value function of dynamic program
Approximate Dual Dynamic Programming

Step 1
Generate a Scenario Lattice

Continuous Process

Lattice Process

Optimal quantization

Step 2
Approximate the Value Function

\[ V_t(F_t, R_t) \]

Value function
Supporting hyperplane
Piecewise-linear approximation

Continuous Process
Lattice Process
QUASAR®: stochastic programming that scales.


QUASAR® in a Nutshell

**OUT-OF-THE BOX PERFORMANCE**
QUASAR® can solve problems with thousands of stages as well as high-dimensional

**STOCHASTIC TIME SERIES MODELS**
Any parameter in the objective function or constraints can be represented by stochastic

**ALGEBRAIC MODELING LANGUAGE**
QUASAR®s modeling language is easy-to-use and lets users model decision problems as if
Discretize PFC Dynamics to Lattice

1. Empirical distribution of daily returns of the PFC
2. Create a lattice by simulating empirical PFC returns
3. Set forward prices to expected spot prices (martingale)

10 nodes per stage

100 nodes per stage
Case Study: Hydropower Portfolio

Data
- Historical production of Alpine hydropower portfolio
- Historical German Base PFCs from EIKON (fair value)
- Regression model of market impact cost

Model
- 730 decision stages (days)
- Endogenous states: Tradable futures contracts and those in delivery
- Exogenous states. PFC, volumes

Procedure
- Create independent lattices of volumetric risk and PFC dynamics
- Solve optimization problem using QUASAR
- Simulate optimal decision policy
Examplary Dynamic Hedge Plan
Here: hedging for 2020 starts at the beginning of 2019

- Shaded areas cover [0.05,0.95]-quantiles
- Purpose of hedging is to minimize risk at minimal cost!
Effect of Volumetric Risk on Hedge Ratios

without volumetric risk

with volumetric risk
Hedging the Term Structure Risk

Distribution of paid price without volumetric risk

Distribution of paid price with volumetric risk
Decision Support for Daily Trading
### Backtest for Deterministic Targets

Did the hedge make money? → Meaningless!

<table>
<thead>
<tr>
<th>Price in €</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
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<td></td>
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<td>30.86</td>
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<tr>
<td><strong>Corridor</strong></td>
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<td>31.35</td>
<td>27.47</td>
<td>25.27</td>
<td>31.72</td>
<td>42.96</td>
<td>31.76</td>
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<tr>
<td><strong>Dynamic</strong></td>
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<td></td>
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<tr>
<td></td>
<td>32.00</td>
<td>27.34</td>
<td>27.68</td>
<td>33.31</td>
<td>45.94</td>
<td>33.26</td>
</tr>
</tbody>
</table>

- Did the hedge make money? → Meaningless!
- Purpose of hedging is to minimize risk at minimal cost
Summary

1. Propose model-driven approach for hedging renewable power portfolio
2. Model takes term structure dynamics and liquidity cost into account
3. Observation: hedging term structure risk is less effective in the presence of volumetric risk
4. Future work: storage provides a natural hedge against volumetric risk but can it reduce term structure risk?
References


- Secomandi, N. and Yang, B., 2021. Quadratic hedging of futures term structure risk in merchant energy trading operations. Available at SSRN.
Efficient Frontier of Different Hedge Plans

- Optimized Dynamic Hedging
- Static hedge plan

Profit vs. Risk (Std Dev)
Lattice of Volumetric Uncertainty