Pricing Virtual Power Plants (VPP) under a Lognormal Swap Market Model
A Trader’s Model

Dr. P. Schuetterle

Structured Trading FPS
E.ON Energy Trading SE
Outline

• E.ON Energy Trading
• VPP contracts & Asset-Backed Trading
• Valuation of VPPs
• Spread model
• Model Inputs
• Conclusion
We are at the commercial heart of E.ON

We are responsible for the commercial interests of E.ON which result from

- About 60 GW of power generation capacity in Europe
- Natural gas sales of >1,000 TWh
- 30 million customers in the EU
We optimize E.ON’s assets and actively manage price risks

E.ON Energy Trading is responsible for commodity risk management and the optimization of E.ON’s assets 3 years prior to delivery.

By actively trading on the futures markets, we minimize the price risks for E.ON’s power production.
We unite the entire trading expertise of E.ON

- We trade in all major European markets.
- We are active at all major exchanges.
- We are active in 40 countries.
- All E.ON’s European trading expertise is united in Düsseldorf.
We have a large stake in the international energy markets*

- Power: 1,240 TWh
- Gas: 1,498 TWh
- CO2 allowances: 501 million t
- Oil: 69 million t
- Coal: 223 million t
- Adjusted EBIT: 949 million €

(*All numbers cited are for 2009)
VPPs & Asset-Backed Trading
Asset-Backed Trading is a style of commodity trading...

- Seeks to exploit market volatility to monetise operational asset flexibility
- Views physical assets as portfolios of traded instruments
- Example: a merchant power plant considered as a strip of spread options
- Use of pricing and modelling techniques adapted from financial markets
Asset-Backed Trading at the Structured Desk comprises...

- Market making for VPP contracts
- Volatility trading and forward spread optimisation
- Management and mitigation of physical and financial risks

Main risks transferred from plant hedger:
- Market price risk (revenues must cover debt servicing & IRR)
- Technical/asset trip risk
- FX-exposure
VPPs are the workhorses of asset-backed power trading...

• Bespoke synthetic power asset contracts, increasing standardisation
• Retain some physical plant characteristics (e.g. start cost, ramp rates)
• Modelled as strip of spread options
• Premium reflects operational constraints and residual risks

Example VPP transaction: A sells to B a virtual coal-fired plant with daily baseload nomination rights

\[
\text{Premium} = 0.45 \times \text{Coal}_{\text{API2}} / \text{FX}_{\text{EURUSD}} - 0.9 \times \text{EUA}_{\text{Dec11}}
\]
VPP Valuation
Strip of Daily Options

- Consider a VPP contract with daily exercise rights
- In absence of physical constraints value as a strip of daily spread options

Payoff = \( \max(0, w_1 S_1 - w_2 S_2 - w_3 S_3 - K) \)
Valuation based on Tradables

Estimate of the value of each option in the strip based on the tradables in the current market structure i.e. Cal, Q, seasonal etc.
Spread Option Model
Spread Option Model

- Model the underlying swap rates as martingales under the risk neutral measure
- One driving factor for each underlyer and traded contract in the current market structure i.e. Cal, Q etc.
- Time dependent but deterministic volatility function

\[
\frac{dF(t, T_i)}{F(t, T_i)} = \sigma(t, T_i) dW_{T_i}(t) \quad \text{i=1,2,...,N}
\]

\[
\Leftrightarrow \quad F(t, T) = F(0, T) \exp\left(\int_0^t \sigma(s, T) dW(s) - 0.5 \int_0^t |\sigma(s, T)|^2 ds\right)
\]

Assume further a correlation structure of the Wiener increments

\[
E[dW_{T_i}(t)dW_{T_j}(t)] = \rho_{ij} dt
\]
Spread Option Model

• The value of the VPP contract per MW of power capacity is then given by

\[ VPP = \sum_{i,\text{strip}} e^{-r^*(T_i-t)} E_t^Q \left( (w_{1,F_{i,1}} - w_{2,F_{i,2}} - w_{3,F_{i,3}} - K)^+ \right) \]

• The value of each spread option in the strip is given by the discounted risk-neutral expectation of the option’s payoff.
• This expression is sufficiently easy to evaluate, e.g. by Monte Carlo simulation.
• Greeks are easily estimated as sensitivities of the VPP price w.r.t. to the underlying value drivers.
• Some similarity to the approach followed by LIBOR models in the interest rate space in the sense that tradables are the building blocks
Inputs: Volatility & Correlation
Forward Volatility Calibration

We have the relationship for the instantaneous volatility with the implied volatility given by

\[ \sigma^{im}_F(t,T_i) = \sqrt{\frac{1}{T_i} \int_0^{T_i} \sigma^2(u,T_i) du} \]

Consistent with market observation write volatility in a parsimonious parametric form

\[ \sigma(t,T_i) = \sigma_1 + \sigma_2 e^{-\kappa(T_i-t)} \]

\( \sigma_2 \) Short-term vol level
\( \sigma_1 \) Long-term vol level
\( \kappa \) decay factor

• Forward volatility depends on time to expiration \((T-t)\) rather than absolute time \(t\)
• Exponentially decaying volatility function (for each underlying leg)
• Can account for length of underlying swap delivery (Kiesel 2007, Benth 2008)
Forward Volatility Calibration

Given the parametric form for the instantaneous volatility we find for the model implied volatility:

\[
\sigma_{imp}^{F(0,T_f)} = \sqrt{\sigma_1^2 + \frac{2\sigma_1 \sigma_2 (1 - e^{\kappa T})}{-\kappa T} + \frac{\sigma_2^2 (1 - e^{2\kappa T})}{-2\kappa T}}
\]

Robust estimation of the parameters of the local volatility function by least squares procedure, i.e. solve

\[
\min_{\{\sigma_1, \sigma_2, \kappa\}} \sum_{mktquotes} \left[\sigma_{imp}^{F(0,T_f)} - \sigma_{model}^{F(0,T_f)}\right]^2
\]

P. Schuetterle, Structured Trading, E.ON Energy Trading S.E.
Correlation Input

• Difficult to imply from the market -> estimation from historical data (requires long time series)
• Estimate fuel-to-power, fuel-to-$\text{CO}_2$, $\text{CO}_2$-to-power and FX correlations for Cals, Qs, months, weeks
• The crucial quantity for valuing and hedging European options is the terminal correlation

$$\rho(t, T) = \rho_{\ln S_T, \ln G_T} = \frac{E_t[\ln S_T \ln G_T] - E_t[\ln S_T]E_t[\ln G_T]}{\sqrt{\text{var}[\ln S_T]}\sqrt{\text{var}[\ln G_T]}}$$
Overview

VPP Contract

Forward curves → Blended Volatility

Implied Volatility for traded Gas & Power products (Cal, Q, M, season etc)

Historical Volatility -> exponentially decaying shape

Historical Correlation Matrix

Premium & Greeks
Model works very well...

• Low tracking error - almost perfect replication of a OP dark spread VPP
...and meet‘s the trader‘s model desiderata:

• Link valuation to practical hedging strategy
• Fast calibration to market implied volatilities
• Fast premium and Greeks
• Ability to correctly price vanilla products traded in the market
• Transparency of model allows intuitive interpretation of the deal value‘s sensitivity w.r.t. drivers/inputs (correlations, volatilities)
• Philosophy: As complex as necessary as simple as possible
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Contact us

E-mail: peter.schuetterle@eon.com
Structured Trading FPS, E.ON Energy Trading S.E.

Holzstrasse 6,
40221 Düsseldorf, Germany

T +49 (0)211-73275 - 5703
F +49 (0)211-73275 - 2320