Energy Options

Examples from Natural Gas and Power Markets & Some Considerations for Valuation

June 2020, Tim Schulze, Structuring & Valuation

Agenda

1. Introduction
2. Options: Basic Definitions
3. Valuing & Hedging Options
4. Examples (Physical Assets & Contracts)
5. Wrap-up & Discussion

Structuring & Valuation

Who we are and what we do:

- Part of Vattenfall's Analysis department
- 11 people with backgrounds in Mathematics, Physics, Economics, Engineering & Computer Science
- Locations: Stockholm (3), Hamburg (4), Amsterdam (4)
- Core tasks: market valuation of assets, (structured) options & other deals
  - Full supply (customer) deals for gas and electricity [NL, DE, BE]
  - Power purchase agreements (PPAs) for wind & solar power [NL, UK, Nordics]
  - Gas storages and swing contracts [NL, DE]
  - Conventional power plants [NL, DE]
  - Other options, e.g. location spreads, commodity spreads
- The common theme: all valuations are done under uncertainty and most of the valued items include flexibility
- This is why we look at most deals from an option theory perspective

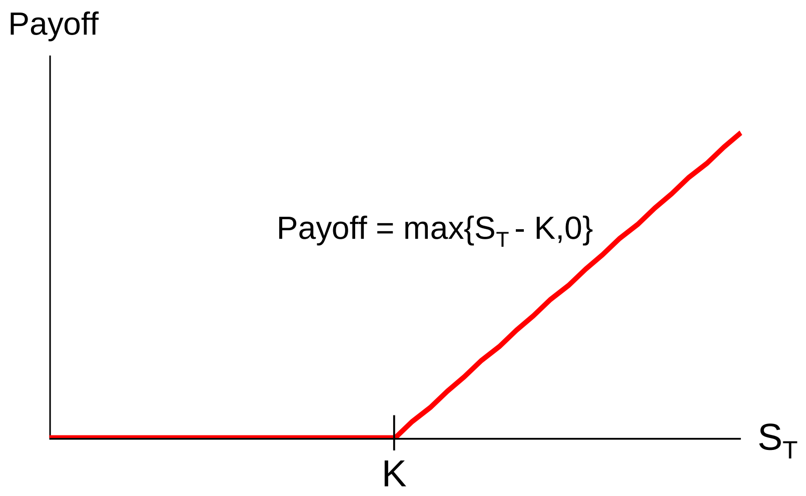
Options: Basic Definitions

- An option is a contract that gives its buyer the right, but not the obligation to buy (call) or sell (put) an underlying asset at a predetermined price (strike price) at or before a future point in time (expiry date)
- Examples of underlying assets: stocks, currencies, other commodities [power, gas, coal, …]
- In return for granting the option, the seller collects a payment (premium) from the buyer
- Options are a means of trading flexibility: The seller has a short position and the buyer has a long position on flexibility
- On the next slides: a (basic) guide to the option terminology jungle

Options: Basic Definitions

- A **call** option grants the right to **buy** the underlying at the strike price

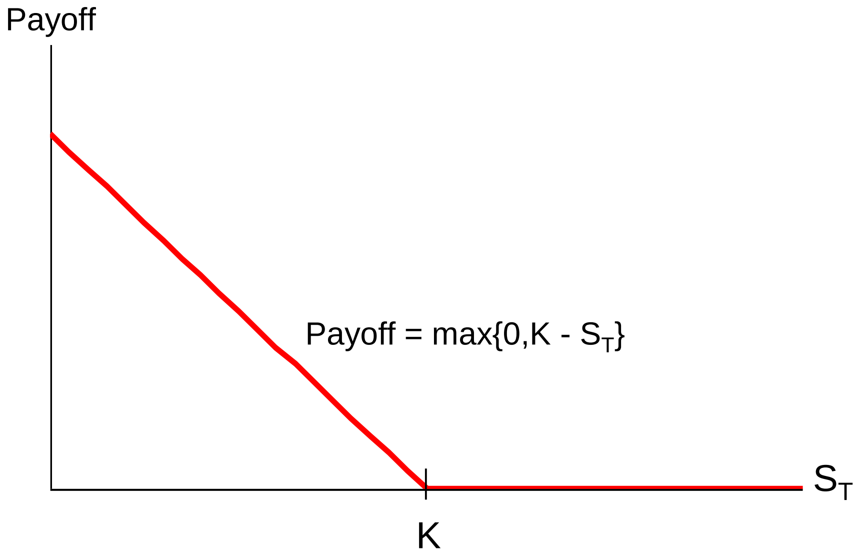
- On the expiry date, the payoff of the option holder looks like this
  - $T = expiry\ date$
  - $S_T\ = market\ price\ of\ the\ underlying\ at\ expiry$
  - $K\ = strike\ price$



Options: Basic Definitions

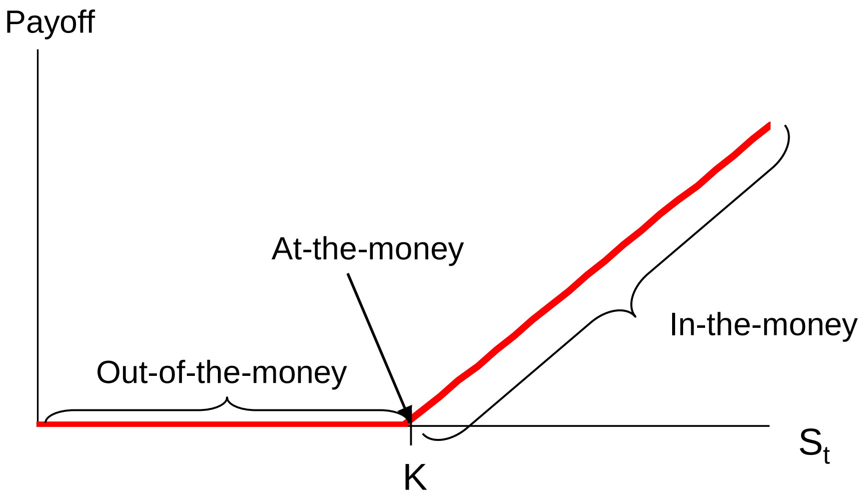
- A **put** option grants the right to **sell** the underlying at the strike price

- On the expiry date, the payoff of the option holder looks like this
  - $T = expiry\ date$
  - $S_T\ = market\ price\ of\ the\ underlying\ at\ expiry$
  - $K\ = strike\ price$



Options: Basic Definitions

- Let t be the valuation date (e.g. current date)
- An option is **at-the-money** when $K = S_t$
- An option is **in-the-money** when $K < S_t$
- An option is **out-of-the-money** when $K > S_t$



Options: Basic Definitions

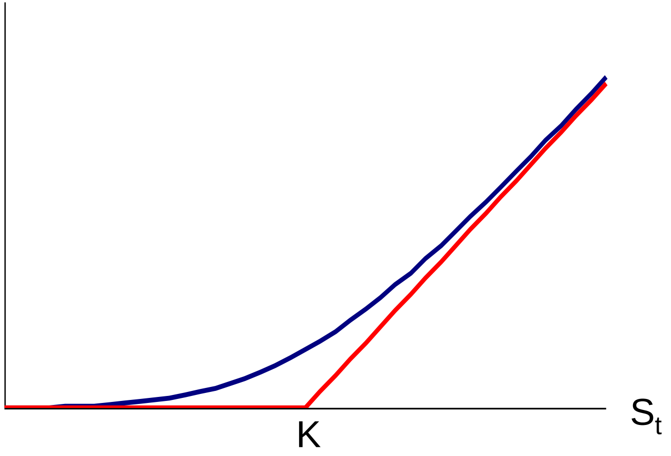
- A **European** option can be exercised only at the time of expiry
- An **American** option can be exercised at any time up until expiry
- A **structured** option combines different options into one contract, e.g.
  - Different underlying assets can be combined into one contract
  - A contract may allow multiple exercises up until expiry
  - …

Options: Basic Definitions

- Let $x(s)$ be the optimal exercise volume at price s
- The **intrinsic** value of an option is the value if it was due for exercise now: $S_t \mathrm{x}(S_t)$
- If there is some time left until expiry, the price at expiry, S_T, is uncertain. The expected option value is called **full** value or **fair** value

$$V(S_t) = \int x(s_T)(s_T - K)f(s_T|S_t)ds_T$$

- Under the assumption that the current price is the expected future price: fair value ≥ intrinsic value
- The difference between fair value and intrinsic value is called **extrinsic** value
- The extrinsic value is highest when $S_t = K$



Blue = full (fair) value
Red = intrinsic value

Hedging Against Risk

Managing an option (portfolio):

- If a trader buys an option for the full value (premium = V), she takes on the risk of losing V (option may become worthless at expiry)
- To mitigate (hedge against) this risk, she can perform forward (or future) trades

Intrinsic hedging examples (no discounting)

Option 1:

Market	DE Power
Type	call
Volume	100 MW
Delivery period	July 2020
Strike price	24 €/MWh
Market price	25 €/MWh

Intrinsic hedge: sell 100 MW of July'20 @25€/MWh

Net (current) value:

100 MW * 744 hours * (25 – 24) €/MWh = 7,440€

Option 2:

Market	DE Power
Type	call
Volume	100 MW
Delivery period	July 2020
Strike price	26 €/MWh
Market price	25 €/MWh

Intrinsic hedge: sell 0 MW of July'20

Net (current) value:

0 MW * 744 hours * (25 – 26) €/MWh = 0 €

Hedging Against Risk

Hedging strategies

1. Dynamic intrinsic hedging:
   - transact (on forward market) the full option volume if and only if the option is in the money right now
   - Fluctuates between fully hedged and not hedged at all
   - Possibly requires many forward trades if the option is close to the money (= high hedging cost)
   - May result in no hedging at all if the option is far out of the money
2. Dynamic delta hedging
   - If $V(S_t)$ [€] is the full option value at current market price S_t [€/MWh], transact $\frac{dV}{dS_t}$ [MWh] on the forward market
   - Idea: take a forward position which neutralizes the option’s exposure to price risk
   - Hedge volume changes in small increments from day to day
   - Hedge volume hardly ever reaches full option volume or zero
3. Advanced hedging
   - Beside delta, calculate derivatives of option value with respect to other variables (e.g. volatility, time to expiry)
   - Seek a portfolio composition which balances these risks in the desired way

Basis for activities (2.) and (3.): regular calculation of the fair value and its various derivatives

Option Valuation

1. Closed form (analytical formulae)
2. Numerical approaches
   - Gauss-Hermite integration
   - Monte-Carlo simulation
   - …

Option Valuation

<u>Closed form valuation of European options with analytic formulae:</u>

- Assume $S_\tau^i\ \{\tau = \mathrm{t}, \dots, \mathrm{T}\}$ follow correlated geometric Brownian Motions (GBM) and exercising optimally is trivial
- Then analytic formulae can be used to calculate or approximate the expectation V and its derivatives
- Very popular: fast & easy calculation of fair value and its derivatives

<u>An overview of popular formulae (incomplete by far):</u>

Payoff	Formula(e) published by	Type
$\max\{0, S_T^1 - K\},\ \mathrm{K} > 0$	Black & Scholes (1973)	Exact
$\max\{0, S_T^1 - S_T^2\}$	Margrabe (1978)	Exact
$\max\{0, S_T^1 - S_T^2 - K\}, \mathrm{K} > 0$	Kirk (1995), Bjerksund & Stensland (2006)	Approximate
$\max\{0, S_T^1 - S_T^2 - S_T^3 - K\}, \mathrm{K} > 0$	Bjerksund & Stensland (2011), Green (2015)	Approximate

Expectation in the bottom case:

$$V(S_t^1, S_t^2, S_t^3) = \iiint q * \max\{0, S_T^1 - S_T^2 - S_T^3 - K\} * f(S_T^1, S_T^2, S_T^3 | S_t^1, S_t^2, S_t^3)\, dS_T^1\, dS_T^2\, dS_T^3$$

q is the contract volume and $f(\cdot)$ is the joint probability density of the prices

Option Valuation

Option valuation with numerical approaches:

1. Gauss-Hermite quadrature
   - Works out-of-the-box for (structured) European options
   - Requires the price distribution at expiry to be Normal (e.g. satisfied for GBM)
   - Fast & accurate, but obtaining derivatives requires (possibly lengthy) calculations
2. Monte-Carlo Simulation
   - Works for all options (European, American, …)
   - Works with non-trivial exercise rules (e.g. a power plant dispatch optimizer)
   - Works with all price processes
   - Computationally expensive
   - Calculation of derivatives requires shifting & repeating (except Delta)
3. Many others. See e.g. review paper by Carmona & Durrleman (2003) ”Pricing and Hedging Spread Options”

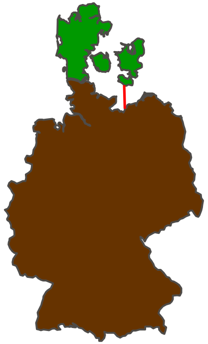
Option Example I

<u>HVDC interconnector</u>

- An interconnector is a daily strip of European call options on the spread between power prices in two market areas
- Expiry: daily. Decide every day on which hours of the next day to operate, and in which direction.
- Let K be the variable cost of operation and S_T^1, S_T^2 be the power prices in the two market areas
- The payoff is $\max\{|S_T^1 - S_T^2| - K, 0\} = \max\{S_T^1 - S_T^2 - K, 0\} + \max\{S_T^2 - S_T^1 - K, 0\}$

<u>Valuation alternatives:</u>

1. Analytic approximation (e.g. Kirk's formula): the value on each day is the sum of the values of two European call options
2. Gauss-Hermite quadrature: not necessary to view the asset as two options per hour. Results may be slightly more accurate than (1.)
3. Monte-Carlo simulation: more effort, especially to obtain derivatives. In this case only necessary if the GBM price model underlying (1.) and (2.) is not good enough.



<u>Kontek Sea Cable (HVDC)</u>

- Germany <>Denmark
- Since 1996
- Capacity: 600 MW
- Length: 170 km
- Grid level: 440kV

Option Example II

Coal power plant:

- A coal power plant is a daily strip of European options on the spread between three underlyings: power, coal and CO2 emission certificates
- Expiry: daily with restrictions. Decide each day how much power to produce in each hour of the next day.
- Let K be the cost of operation and S_T^P, S_T^C, S_T^{CO2} the power, coal and emission prices, respectively
- The (per MWh) payoff in hour T is approximately $\max\{S_T^P - \lambda^C S_T^C - \lambda^{CO2} S_T^{CO2} - K, 0\}$. This is called **clean dark spread**.

Power plants are complicated:

- Properties & restrictions:
  - K includes start-up cost and fixed running cost
  - λ^C, λ^{CO2} are hyperbolic functions of the power output
  - Minimum and maximum stable generation limits
  - Minimum up- and downtimes
  - Ramping rates
- GBM is not a suitable price model for CO2 emissions
- Preferred valuation method: Monte-Carlo simulation with dispatch optimization (Dynamic Programming) for each price scenario individually

Moorburg coal power plant (Hamburg)

- CHP plant with 2 x 800 MW capacity
- In operation since 2015
- Dispatched for power production, but provides district heating

Option Example III

Natural gas storage:

- A gas storage is an American option on the time spread between natural gas prices in the same market
- Expiry: daily with restrictions. Decide each day how much to inject/withdraw on the next day
- Let K be the cycle cost and S_T^{Q1}, S_T^{Q3} be the average spot price in the relevant injection/withdrawal periods
- The (per MWh) payoff in a given storage year is $S_T^{Q1} - S_T^{Q3} - K$

Gas storage valuation:

- Tomorrow's optimal dispatch depends on
  - Current storage level
  - Expected future dispatches (given the current forward market view)
- Injection/withdrawal capacities are functions of the storage level
- Preferred valuation method: Monte-Carlo simulation with a full stochastic dispatch optimization (e.g. Least-Squares-Monte-Carlo algorithm)
- Perfect foresight optimization per scenario (the power plant approach) overvalues American options significantly

Epe gas storage (Gronau, Germany)

- Capacity: 2.75 TWh
- Injection: ~3GW
- Withdrawal: ~5GW
- Leading market: TTF (NL)
- Secondary market: NCG (DE)

Option Example IV

Swing contracts:

- A swing contract is a popular American option. It is a supply contract (e.g. gas, oil, power,…) that includes flexibility on the total volume and on the daily volume
- Swing options are almost always call options
- Expiry: daily with restrictions. Decide each day how much of the commodity to take on the next day.
- Let K be the strike price and S_T be the spot price on day T. The (per MWh) payoff upon exercise is $S_T - K$.

Swing contract valuation:

- Tomorrow's optimal exercise depends on
  - All past exercises
  - Expected future exercises (given the current forward market view)
- Preferred valuation method: Monte-Carlo simulation with a full stochastic dispatch optimization (e.g. Least-Squares-Monte-Carlo algorithm)

A swing contract:

Delivery period	Q1 2021
Market	TTF
Type	Daily call
minDCQ	0 GWh
maxDCQ	4.8 GWh (= 200MW)
minTCQ	216 GWh (= 45 days)
maxTCQ	288 GWh (= 60 days)
Strike	1-0-3 indexed

Wrap-up & Discussion

- Options are ubiquitous in energy markets
- To manage an option portfolio, we need to calculate the fair option value and its derivatives
- Depending on the option, different approaches are necessary:
  1. Analytic formulae
  2. Numerical quadrature
  3. Monte-Carlo simulation
  4. Other numerical procedures

Questions?

Some Literature

- Eydeland & Wolyniec: ”Energy and Power Risk Management” (2003), Wiley
- Carmona & Durrleman: ”Pricing and Hedging Spread Options” (2003)
- Green, R.: ”Closed Form Valuation of Three-Asset Spread Options With a view towards Clean Dark Spreads” (2015)
- Boogert & de Jong: “Gas Storage Valuation Using a Monte Carlo Method” (2006)
- Boogert & de Jong: “Gas Storage Valuation Using a Multi-Factor Price Process” (2011)
- Longstaff & Schwartz: “Valuing American Options by Simulation: A Simple Least-Squares Approach” (2001)
- Jaeckel, P.: “A Note on Multivariate Gauss-Hermite Quadrature” (2005)