# Stochastic models for electricity markets
# Lecture 02 - Introduction to electricity markets

## Frontiers in Stochastic Modelling for Finance
## Winter School - Università degli Studi di Padova

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# Agenda


1. Electricity markets microstructure
   - Intraday market
   - Day-ahead market
   - Forward market
   - Capacity market
2. Energy Markets Financial Regulation
3. Derivatives & Risk management
   - Power plants & tolling contracts
   - Energy storage & swing contracts
   - Other derivatives
4. Conclusion
5. References

# Electricity markets microstructure

# Common market structure for a local commodity

## Comments

- Electricity is a local commodity.
- As many electricity market as they are states
  - Europe: EEX (Germany), NordPool (Scandinavia), Elexon (Great Britain), Epex Spot (France),...
  - North America: CAISO (California), NYISO (New York), PJM, ERCOT (Texas), IESO (Ontario, CND), AESO (Alberta, CND)
  - South America: EECC (Brazil), Chile
  - Asia and Oceania: Philippines, Singapore, Australia, New-Zeland
- Market microstructure highly depends on national regulation.
- Nevertheless, common structure emerges driven by the necessary equilibrium between consumption and production.

# Common market structure

## A sequence of markets ordered by time-horizon

- The intraday market and/or balancing mechanism
- The day-ahead market
- The forward market

## A market introduced to solve investment in peaking plants

- Capacity market

# Intraday

## Commons

- Ensure the security of the system → Balancing Mechanism.
- Transparent market price for the cost of imbalance → Imbalance Settlement Price.

## Remark

- May coexist at the same a market for next hours where firms exchange power.

# Balancing mechanism

## Example French TSO adjustment market mechanism as of April, 2013.

- Balance Responsible Entities (BR) submit bids and offers to increase or decreases their production (or consumption).
- TSO selects offers based on economic precedence.
- BR are paid as bid.
- Every power available plant should be declared on the adjustment market
- Producers declare their price to increase their production
- System operator uses all these offers to insure real-time production consumption equilibrium
- But, some time later, each balance responsible entity receives the bill of her imbalances...

# Balancing mechanism

## Example: French TSO imbalance price settlement mechanism

- $S$ represents the day-ahead price settled the day before for the hour of interest.
- $P^d$ is the average price of the offers used by the TSO on the balancing mechanism to decrease the production (or increase the consumption).
- $P^u$ is the average price of the offers used by the TSO on the balancing mechanism to increase the production (or decrease the consumption).

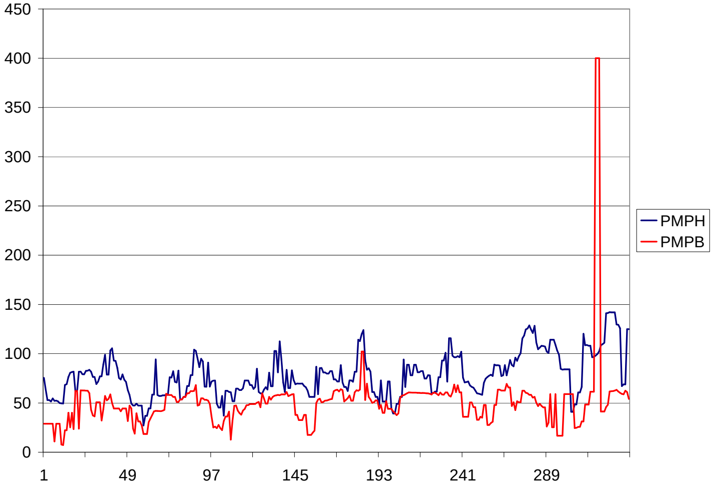
# Imbalance mechanism

| | Network Adjustment Trend Positive | Network Adjustement Trend Negative |
|---|---|---|
| Actor Imbalance Positive<br>Actor is paid | $S$ | $\min\left(S, \frac{P^d}{1+k}\right)$ |
| Actor Imbalance Negative<br>Actor pays | $\max\left(S, P^u \times (1+k)\right)$ | $S$ |

## Lecture

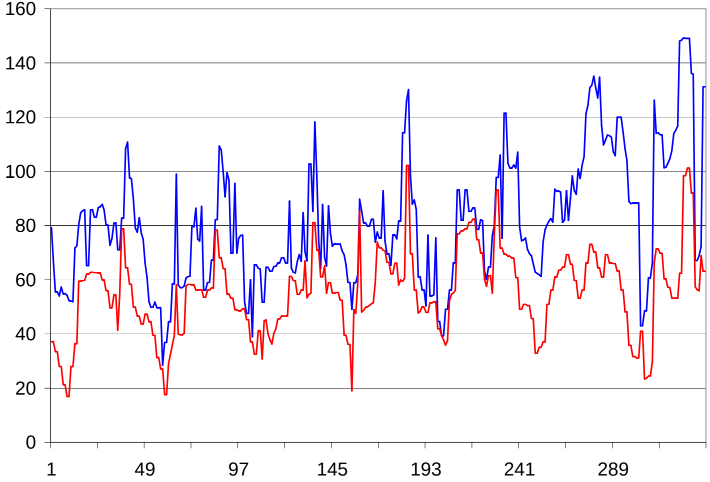
- Network needs downward adjustment & Actor is producing too much $\rightarrow$ Actor is paid $\frac{P^d}{1+k}$ but not more than $S$.
- Network needs upward adjustment & Actor is producing not enough $\rightarrow$ Actor pays $P^u \times (1+k)$ and at least $S$.

# Balancing mechanism




Weigthed Average Upward and Downward adjustment price in French power market from january 4th, to 10th 2010.

# Imbalance prices




Imbalanced Settlement Prices (Upward and Downward) in French power market from january 4th, to 10th 2010.

# Intraday market

## Note

- Beside this balancing mechanism, an intraday market for energy delivery for the hours of the day or of the next day exists.

# Epex intraday market prices

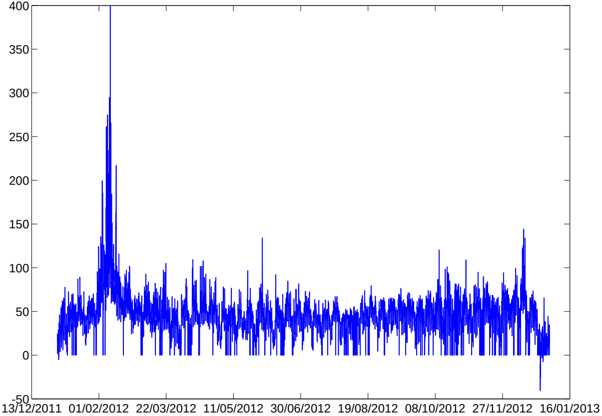



Figure: Epex intraday hourly prices during 2012.

# Day-ahead market mechanism

## Example of Epex spot

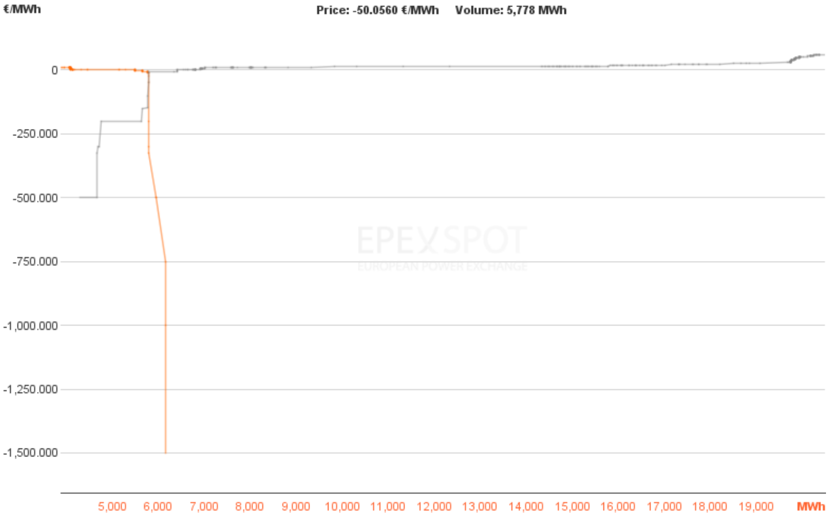
- Based on a fixed trading auction.
- Participants submit bids before a certain time (around 10:00).
- Bids can concern a particular hour of the next day or a set of hours (order block).
- bids of market participants for a particular hour form a bid curve because she can submit a list of prices and quantities.
- Market organizer clears the market: she fixed a price for each hour of delivery and determines the seller and the buyers.
- Market players have then enought time to send production orders to their power plants and send their schedule to the TSO.
- Note: the clearing process results in a non-convex optimization problem (block orders), for which defining a market price requires caution.

# Day-ahead market mechanism

## Trans-countries trading

- In continental Europe, each country has its own electriciy day-ahead market cleared by her own firm.
- Without coordination, resulting quoted prices may provide the wrong signal when compared to transit flow between countries.
- Example given between France and Germany: flows would not follow spot prices difference between countries.
- Since quoted day-ahead prices by market organizer have a transparency function, mechanisms have been developped to ensure a consistent relation between cross-border transactions and local day-ahead prices.
- Market coupling: performing implicit auction mechanism.

# Day-ahead market mechanism



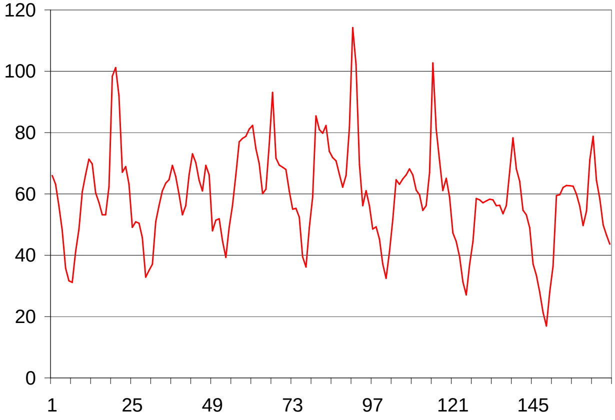
# Market coupling

## Implicit auction mechanism

- In each country, market participant do not have to care about finding a counterparty in neighboring countries.
- She has juste to submit her bid in her country (sell or buy).
- Market organizers perform a clearing process with transport constraints implied by the available transfert capacity (ATC).
- If there is no binding transit capacity constraints, then there will be a single price for the clearing area.
- If there is at least one binding transit capacity constraint, two prices will emerge.

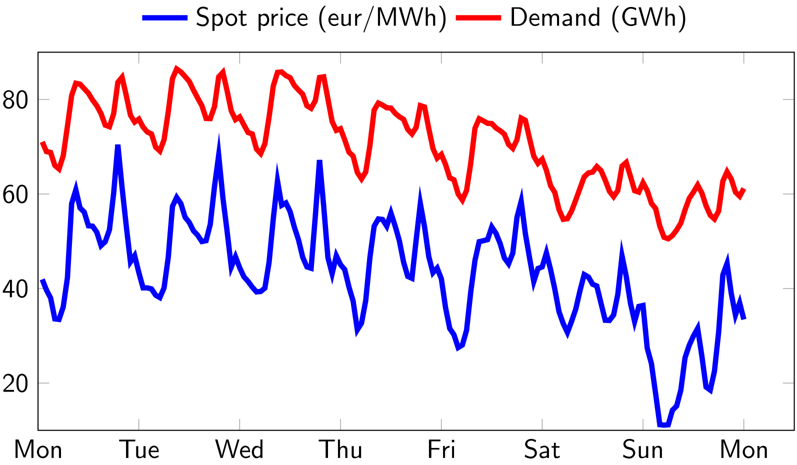
# Day-ahead market price exhibits seasonnalities

Daily and weekly seasonality. Epex hourly spot price, january, 4th to 10th 2010.




Exhibits also, annual saisonnality.

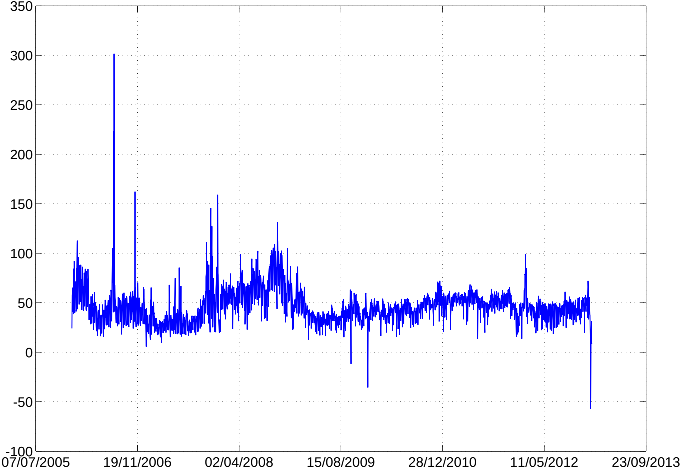
# and strong dependence with consumption




Example of Epex spot ong Janaury, 2012.

# Day-ahead market price exhibits spikes and negative prices

EEX day-ahead price.



# Relation between intraday and dayahead prices

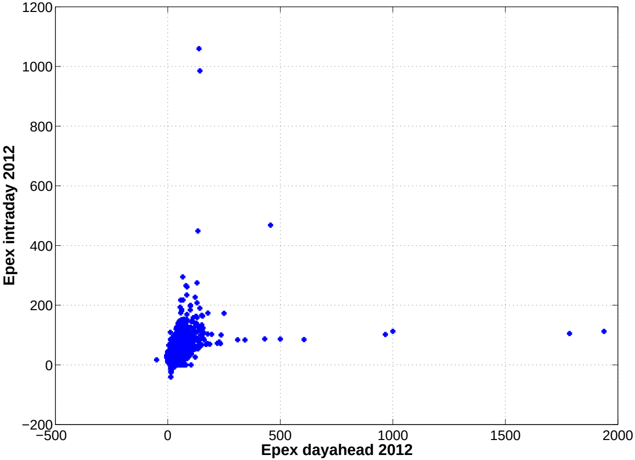



Figure: Epex intraday and dayahead hourly prices during 2012.

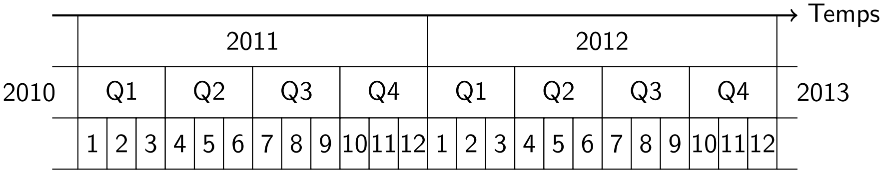
# Comments

**Extreme situations**

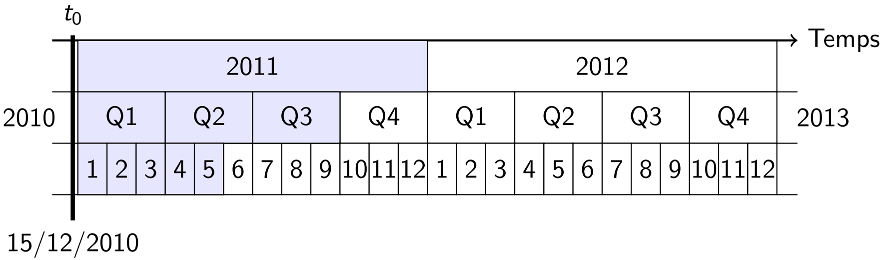
- High day-ahead price and low intraday: uncertainty resolved.
- Low day-ahead and high intraday: very short-term uncertainty realisation.

- Day-ahead market prices is refered as the spot price

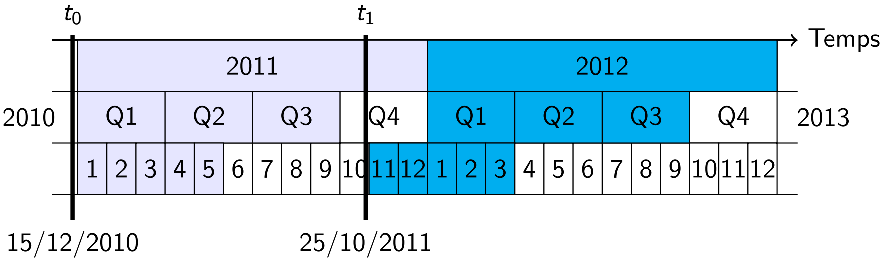
# Forward market nested contract structure



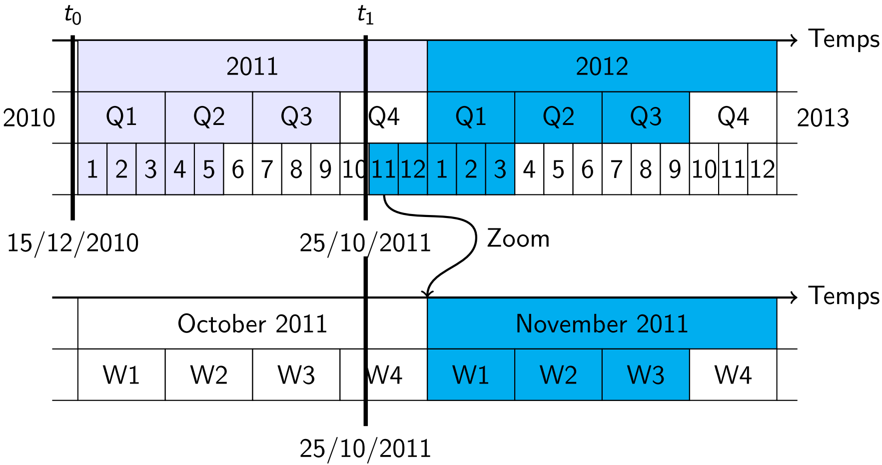
# Forward market nested contract structure



# Forward market nested contract structure



# Forward market nested contract structure



# Available forward contracts

## Example EEX

- Are available at the same time:
  - 6 calendars
  - 11 quarters
  - 9 months
  - 4 weeks
  - 2 weekends
  - 8 days
- In three flavours: baseload (each hour), peakload (07:00-20:00 Monday to Friday) and offpeak (complementary to peakload, not available for weeks, weekends and days).
- Thus, 106 contracts are available
- Compare with the 525,684 hours in the next six years.

# Forward contract settlement

## Settlement

- Electricity forward contracts implies a delivery during a period of time.
- Delivery of power every hour of the week, month, quarter or year (base load) or a set of hours frome Montay to Friday (peak load).
- Possible settlement at maturity or continuously during the delivery period.

# German baseload forward curve dynamic

# German baseload forward curve dynamic

## Comments

- Very differentiated behaviour between spot, month and yearly contracts.
- Slow motion of yearly contracts. May exhibit report or deport configuration.
- Strong seasonal pattern of monthly contracts (blue dots). Dissapears

# German baseload open interest curve dynamic

# German baseload open interest curve dynamic

## Comments

- Close maturities catch all liquidity.
- Linear growth of closest maturity open interest.

# French-German spread curve dynamic

# French-German spread curve dynamic

## Comments

- Strong dependence.
- Possible signe inversion with time and maturity.

# French-German spread curve dynamic

## Comments

- Strong dependence.
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## Who was who?

# French-German spread curve dynamic

## Comments

- Strong dependence.
- Possible signe inversion with time and maturity.

## Who was who?

France is in blue, Germany is in red.

# Capacity market

- Energy only market should be enough to optimise the economic dispatch and the investment decision.
- In practice, difficulties to get day-ahead spot price high enough to cover the investment of a peaking plant (missing money problem).
- Need of peaking plants to ensure reliability of the electric system.
- How to give the right incentives to utilities to invest in peaking plants?
- Different solutions across countries: capacity paiement, strategic reserve, capacity obligation and capacity market.

# Capacity market: the case of the French capacity market

## General principles

- decentralised organisation.
- Retailers must contract *capacity certificates* that match their demand, unless they are exposed to penalties on the balancing market.
- Producers must contract with the TSO a certain level of availability, which will be checked on delivery period.
- 3 to 5 years ahead, TSO produces an estimate of the needed capacity as a margin requirement per retailer for the peak-load demand at certain extreme temperature.

# Capacity market: the case of the French capacity market

## General principles

- Producers gets certificates for their production capacity availability. Procedure varies according to the technology. Producers have the choice on the level of the certificates.
- At maturity, consumption of retailers clients is measured on certain days (PP1) known the day before.
- At maturity, availibility is measured on certain days (PP2) known the day before.

# Capacity market: the case of the French capacity market

## Computation methods

- Mandatory capacity for a retailer = reference consumption on PP1 days × security factor. Security factor reflects the forecasted tension of the system and is published by the TSO on a yearly basis.
- Guaranteed availability for a producer = maximum capacity of the plant × availibility committment at times PP2 × peak-load factor. Peak-load factor takes into account the storage effect of certain production asset.

# Capacity market: the case of the French capacity market

## Capacity market price

- Two possible sources of imbalances:
  - Mandatory players: notified volume of certificates − volume of certificates owned.
  - Certication player: observed level of availability − level of certification.


## Regulated price

To be no more than 40 k€/MW.

# Energy Markets Financial Regulation

# Energy Markets Financial Regulation

## Motivations

- Global impact of 2008 financial crisis
- Credit risk poorly managed
- Systemic risk of some major financial players
- Commodity markets are being more financialised
- Commodities are politically sensitives (specialy energy and agricultural commodities)
- OTC markets are seeing with suspicion compared to exchanges

# Overview of EU regulation framework for financial activities

## Main legislation framework

- MiFID (Markets in Financial Instruments Directive)
  - Directive 2004/39 and 2014/65
  - Investors protection
  - Competition in investment and banking services
  - Concern financial actors (banks, investement bank...)
- CRD (Capital Requirement Directive)
  - Directives 2006/48 and 2006/49
  - Defines the level of capital required to exercise financial activities
  - Concerns financial actors

# Overview of EU regulation framework for financial activities

## Main legislation framework

- EMIR (European Market Infrastructure Regulation)
  - Rules UE/648/2012
  - Regulation of OTC derivatives to decrease risks
  - Concerns financial and non-financial actors
- MAD (Market Abuse Directive)
  - Directive 2003/6 and 2014/57
  - Regulation of market abuse prosecution and criminal sanctions
  - Concern all actors acting on a wholesale market.
- REMIT (Regulation on Wholesale Energy Market Integrity and Transparency)
  - Regulation (EU) No. 1227/2011
  - Regulation of electricity and gas market transparency
  - Concern all actors acting on a energy wholesale and retail markets.

# REMIT

## Objective and calendar

- Will to create a unique wholesale energy market at the European scale
- Will to promote transparency on trading activities
- Put into place between 2011 and present.

## Consequences

- Mandatory reporting of all trading deals to ACER (Agency for the Cooperation of Energy Regulators).
- Reporting include standardized and non standartized deals.
- $\approx$ 8,800 different contracts listed.

# EMIR

## Objective and calendar

- Improve derivative market transparency
- Reduce systemic risk
- Avoid market abuse

## Principles

- Centralised compensation for OTC derivatives assessed by ESMA (European Supervision Markets Authority) [Transparency objective]
- Harmonised legal at the EU level to ensure CCPs (Central CounterParties) comply with strong requirements (capital, organisation, rules) [Licensing requirements for key market infrastructure]
- Operational and counterparty risk mitigation techniques made compulsory for all non-cleared OTC derivatives [Risk Mitagation objective]
- Reporting obligation to Trade Repositories for all derivatives (OTC and listed) [Improving transparnecy objective]

# EMIR - Mandatory central clearing

## Rules

- Apply to Financial Counterparties and not to Non-Financial Counterparties.
- Banks, investment firms, insurers, hedge funds are Financial Counterparties.
- For Non-Financial Counterparties, there is a mandatory clearing obligation for all derivatives if regulatory threshold is breached.
- Threshold defined in Delegate Rule 149/2013 of December, 19th 2012, chapter VII.
- Derivatives: credit & equity 1 billion €, interest rates, foreign exchange, commodities and any other underlying 3 billion €.
- Threshold holds on the gross nominal value.
- Hedging contracts as of IFRS norms or economic hedge are excluded from threshold computation.
- Hedge includes: proxy hedging, macro-hedging.

# Derivatives & Risk management

# Introduction

## Problems

- An electric utility is exposed to a whole set of risk factors:
  - Electricity prices
  - Fuel prices: coal, crude, gas,
  - Emission prices
  - Currencies
  - Consumption and market shares
  - Outtages and inflows
  - Climate
- Many assets can be seen as financial options.

# Option

- Gives the owner the right but not the obligation to take delivery.
- Example: European Call option. Gives the rigth to take delivery at maturity $T$ of the underlying at a pre-defined price $K$, the strike price.
- Since Black & Scholes (1974) seminal work, pricing and hedging of those products have gained important insight.
- The management of physical assets owned by utilities may benefit from this knowledge.

# Real derivatives

- Like any other commodity market, electricity markets have their options on quoted futures.
- But, physical assets can be seen as Real Derivatives.

## Real Derivatives

- Embedded options in producers or retailers portfolio.
- Power plant $\rightarrow$ strip of call options on fuel spread.
- Tolling contracts $\Rightarrow$ structured contract counterpart.
- Water reservoir $\rightarrow$ strip of call options on calendar spread.
- Swings $\Rightarrow$ structured contract counterpart.
- Demand-side management $\rightarrow$ strip of puts.

# Power plants as derivatives

## First approximation of power plants value

- Strip of calls on the spread between its fuel price and the electricity price.
- The value of a power plant on a period of time $[0, T]$ would then be given by :

$$\mathbb{E}\left[\int_0^T (P_t - hS_t)^+ dt\right],$$

where $P$ is the price of power, $S$ the price of its fuel and $h$ its heat-rate and $x^+ = \max(0, x)$.

- There exists a formula for the exchange options (Margrabe's 1978).
- It applies here, gives value and Greeks.
- But, there are some problems with this approximation.

# Difficulties with power plants as derivatives

## Difficulties

- Increasing realism unduces numerical difficulties.
- With emission price, value reads:

$$\mathbb{E}\left[\int_0^T (P_t - hS_t - gS_t^c)^+ dt\right],$$

- No more closed-formula.
- Taking constraints into account (start-up cost act as non-zero strike price. Ramp-up time, minimum power) → optimisation problem.

# Difficulties with power plants as derivatives

## Difficulties

- Black & Scholes framework does not fully apply for the pricing of optionnality of physical assets.
- B&S model relies on the idea that the underlying is perfectly storable and that there are as much risk factors than hedging products.
- In this situation, the value of an option does not depend on the risk preferences of the economic agents.
- In the case of electricity markets, none of these two hypothesis apply.

# Water reservoir and energy storage

## Valuation

- Theoretical difficulties of power plants valuation apply also for hydro power plants
- The limited ressource of fuel leads to a problem a storage management.
- Most simple hydrolic storage management problem deals with a single reservoir.
- The valuation problem writes

$$\sup_{q_t \in [0,\overline{q}]} \mathbb{E}\left[\int_t^T q_u S_u du + g(S_T, X_T)\right],$$

$$dX_s^{t,x} = (a_s^{t,a} - q_s)ds,$$

with $S_t$ the electricity spot price, $X_t$ current level of the water reservoir, $a_s$ random inflows. $X$ is subject to level constraints and should stay within $[\underline{x}, \overline{x}]$. The function $g$ represents a final value for having a certain level of water at a final time.

# Water reservoir and energy storage

## Valuation

- Leads to stochastic control problems
- Intensive use of Dynamic Porgramming
- Main difficulies: dimension state.

# Other derivatives

## Retail contracts

- Tarification policy for different final consumers (industrial, small business and households)
- Financial risk embedded in a client load curve vs portfolio effect.
- Market share vs margin.

## Weather derivatives

- Producers financial risk highly depends on weather.
- Weather derivatives on temperature, rain, wind procure insurance on bad outcomes.

# Conclusion

## Complexity

- Power systems knowledge.
- Nested market microstructure.
- Complex products.
- Incompleteness & valuation.
- Numerical methods for stochastic control problems.

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## Monographies


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