Electricity market models

Deregulated Market

- It is a service area where a TSO/ISO/RTO coordinates the participants and transmission
- Anyone can own a power plant and connect it to the network to sell energy (seller)
- Any wholesale consumer can connect to the network and buy energy (buyer)
- Equal access to the transmission network is guaranteed to each participants

Daily energy auction

- The daily auction is the most important characteristic of a deregulated market
- It is a non discriminatory auction
  - All winning bidders get paid the same price regardless of their bids
- It sets the price and the quantity of the electricity
  - The price of energy for every producer and every wholesale consumer is set to a single price called the clearing price

Marginal price

- The power plants are activated in order of their bids (lowest to highest) until the total demand is met
- The last power plant activated sets the clearing price
- The cost of bringing the last unit of electricity activated plant is called marginal price of energy and the last activated plant is the marginal producer
- The clearing price is set by the marginal price of energy

The day-ahead auction

- The day-ahead auction sets the price of energy for each hour of the following day
- This auction is completed generally in the early afternoon on the day before the delivery
- This allows power producers time to arrange fuel and operating schedules for the delivery day

The real-time auction

- The real-time auction is run continuously throughout the actual delivery day
- This auction balances the actual demand against the predictions made the previous day
- It is typically bid in five minutes (USA) fifteen minutes (EU) increments
- If a power plant is not chosen in the day-ahead auction, it can still participate in the real time auction
  - But, the real time auction requires power plants to turn on and off quickly, and not every plants has this capability

The market and the transmission system

- Transmission lines can become overloaded and may require electricity to be routed around the congestion
- The primary way to reroute power is to activate power plants closer the high demand areas
- As low cost generators are normally activated first, turning on a generator closer to the demand means that a higher cost plant is being activated out of merit order

Market models

Organized electricity markets

- Exchanged products
  - Energy for final consumption and transmission rights
  - Day-ahead market
  - Market operators: generators, consumers, retailers

  - Capacity for generation reserve, real-time balancing, congestion resolution
  - Ancillary service market
  - Market operators: generators, TSO

  - Capacity for generation adequacy
  - Capacity market (other forms of remuneration are possible)
  - Market operators: generators, consumers/TSO

The day-ahead auction market structure

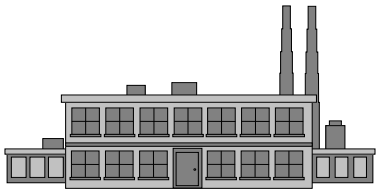
- Central issue: role and level of the regulator vs. those of decentralized decision making by individual market players
- General agreement on the need for coordination of the power system
- The two paradigms:
  - Pool model
  - Bilateral model

Two different paradigms

- Day-ahead market design: two extreme cases
  - Electricity pool (compulsory)
  - Bilateral or OTC (Over The Counter) market

- In real life: mix of the two

The unbundled structure



ESP

end user

load aggregator

DISTRIBUTION (WIRES)

TSO

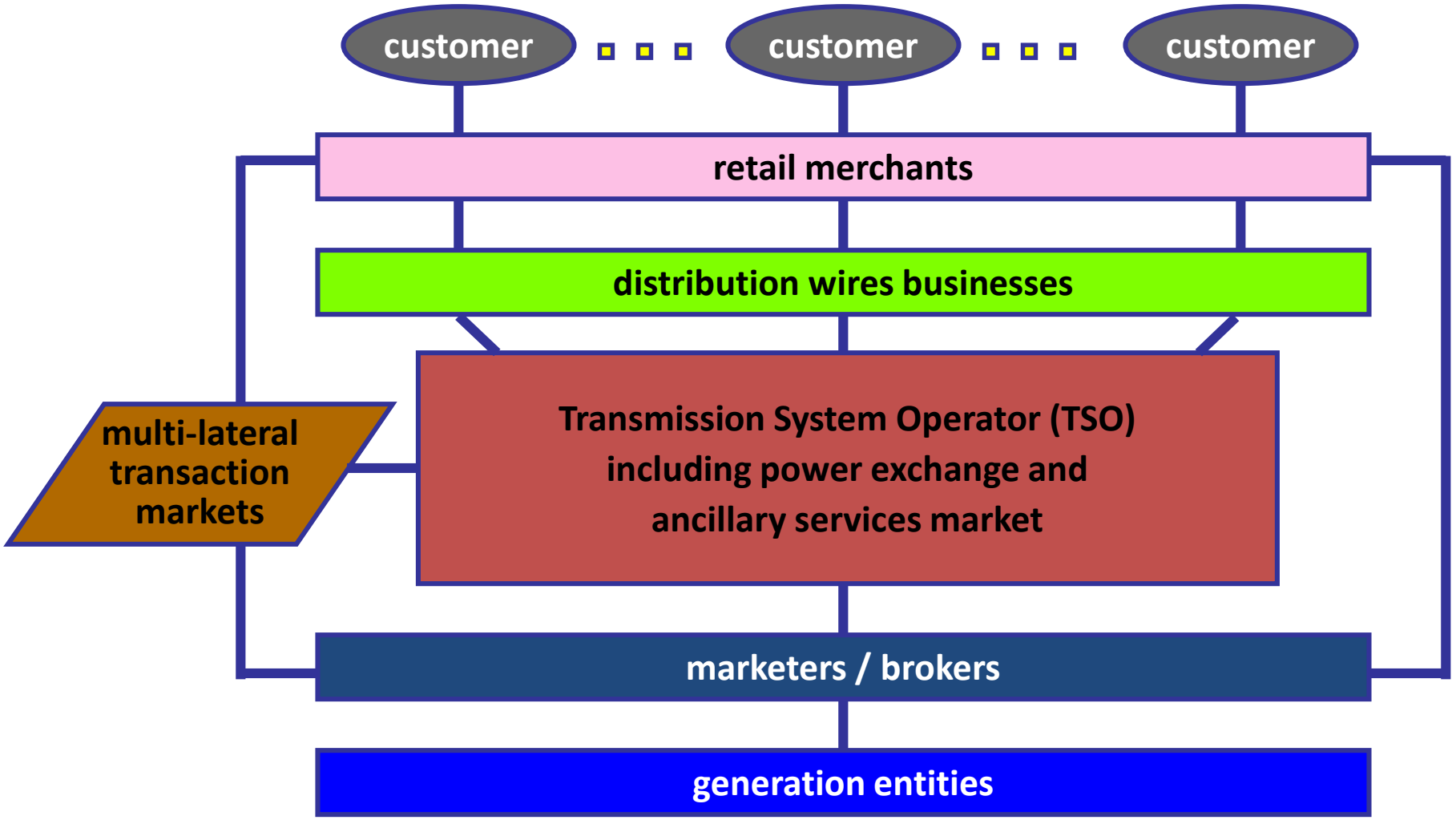
power exchange

ancillary services market

scheduling coordinator

G G G G G G G G G G G G

The pool model



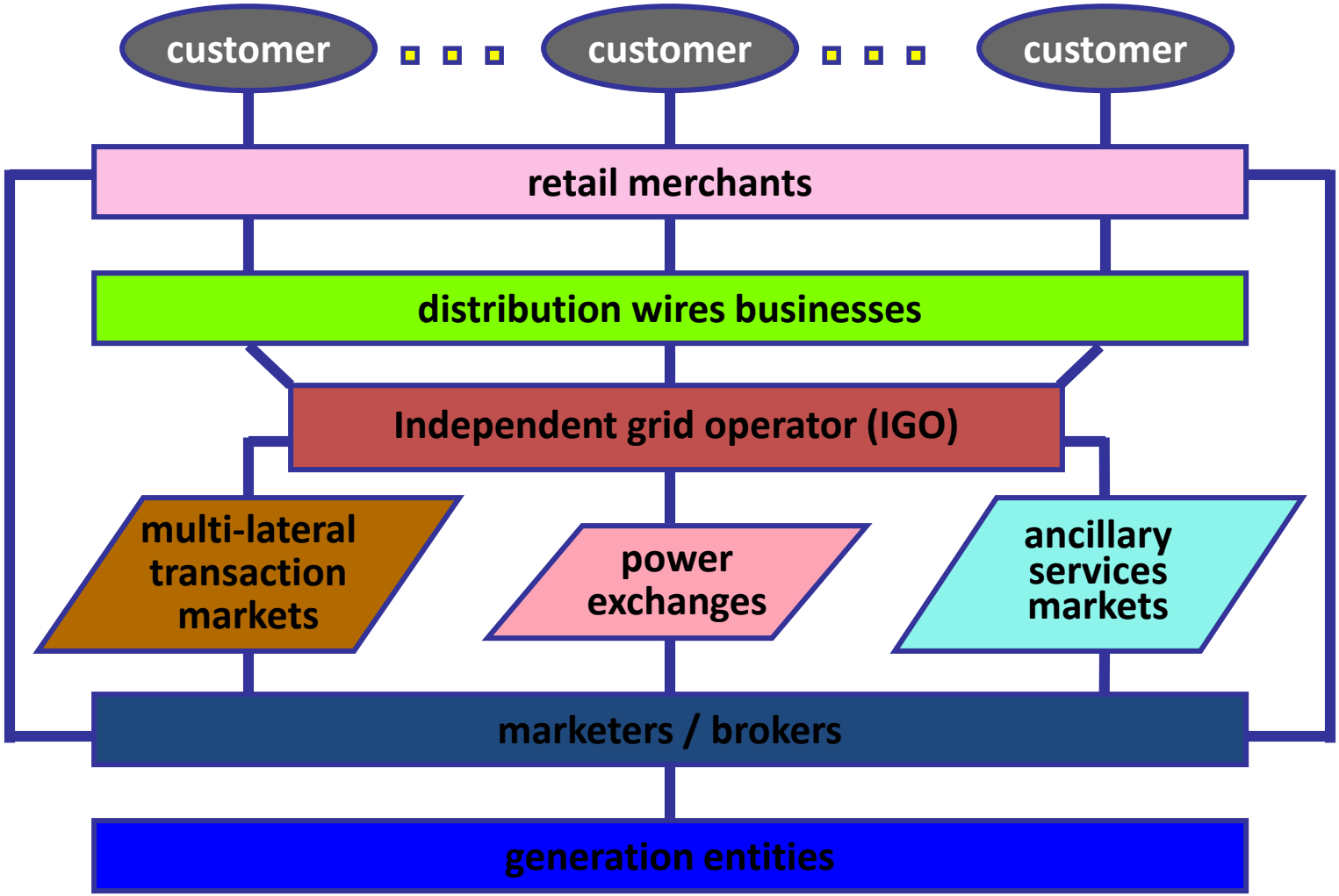
The bilateral trading model

- Players arrange the purchase and sale transactions among themselves
- An entity known as a schedule coordinator (SC) or a power exchange (PX) is responsible for ensuring supply/demand balance
- The independent grid operator (IGO) has the role to facilitate the undertaking of as many of the contemplated transactions as possible subject to ensuring that all system security and physical constraints are not violated

The bilateral trading paradigm

- Coordination between one or more markets and an independent grid operator
- Independent grid operator in charge of system reliability/security
- Bulk energy market consisting of one or more “power exchanges”
- Basic requirement: effective coordination among all players in a decentralized decision-making environment
- Grid operator as air traffic controller in charge of take-offs, landings, congestion but not of prices for airport landing rights or seats on plane

The bilateral trading model



TSO/ISO principles

- Fair and nondiscriminatory governance
- Absence of TSO financial interest in its or its employees' performance in any power market
- Clear and non discriminatory tariff
- Primary responsibility for ensuring the operational reliability of grid
- Control over transmission system operations within the TSO's region
- Ability to identify and manage effectively actions to relieve transmission constraints
- Development of transmission system

TSO/ISO principles

- Incentives for efficient management and administration and for acquisition of ancillary services competitively
- Pricing should promote efficient use of, and investment in generation and transmission and efficient consumption; responsibility for identifying operational problems and appropriate system expansion strategies
- Provide transmission system information to the market
- Coordinate with neighboring control areas

The pool market paradigm

Electricity pool: The PX markets

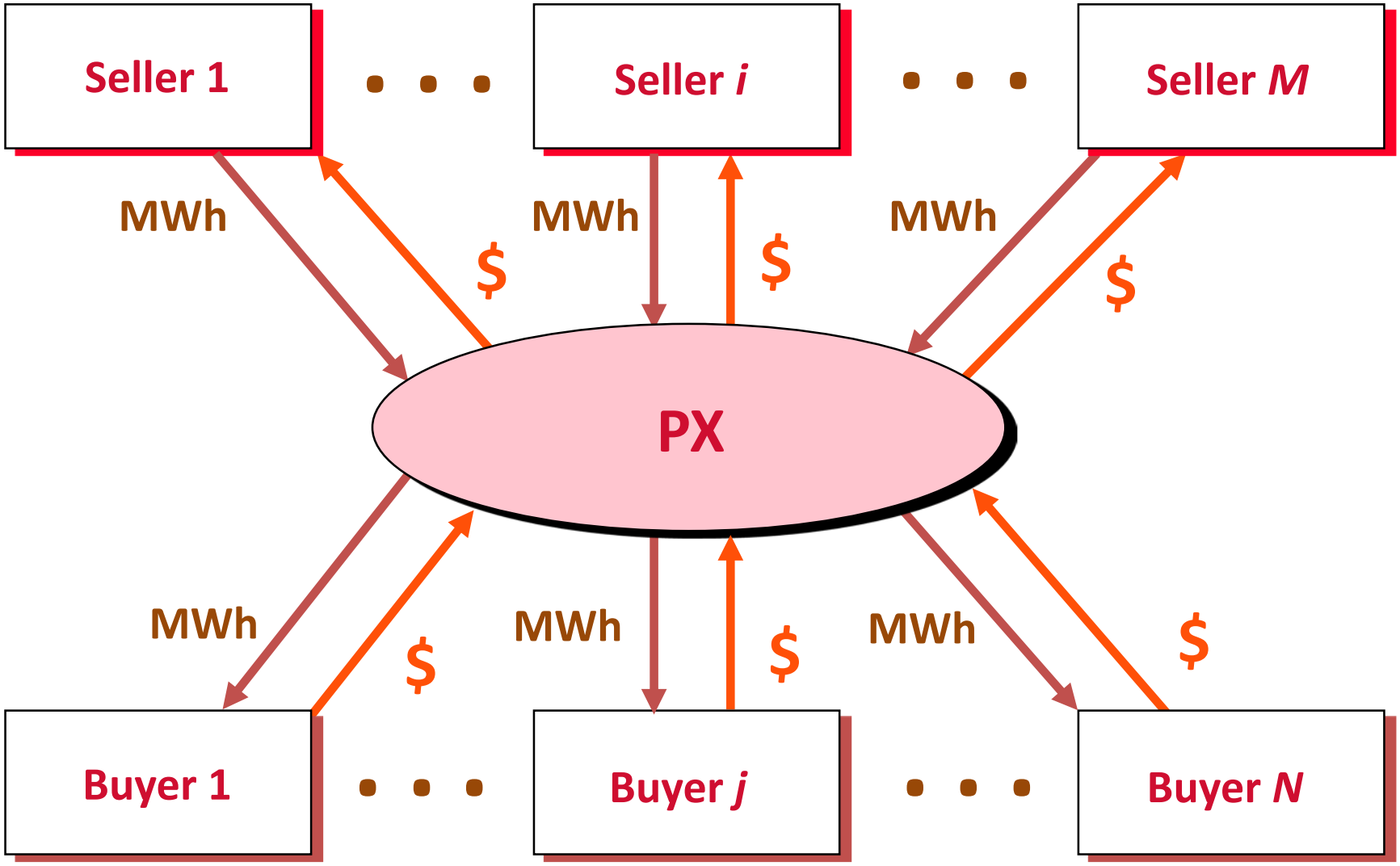
- Day-ahead market is the only buyer for power producers and the only seller for final users

- The PX markets are essentially short-term forward markets in which generators bid for the right to serve load and loads bid for the opportunity to have their demands satisfied
  - auction mechanism establishes the required pre-scheduling
  - schedules are financially binding on generators and loads
  - commitments are virtually physical since widespread violation of PX commitments may bring about disruption of system integrity

Electricity pool: The PX markets

- Sellers: generators, brokers/marketers
- Buyers: consumers, brokers/marketers, distribution and generation entities
- Market Operator (MO) is in charge of the market and uses an auction procedure to determine the prices and quantities sold (for each hour of the following day)
- Sellers and buyers submit sealed offers and bids, describing the price and quantities at which they are willing to sell/buy energy
- The auction results determine the scheduling (unit commitment and dispatch) of the physical units and of the demand served

The electricity pool

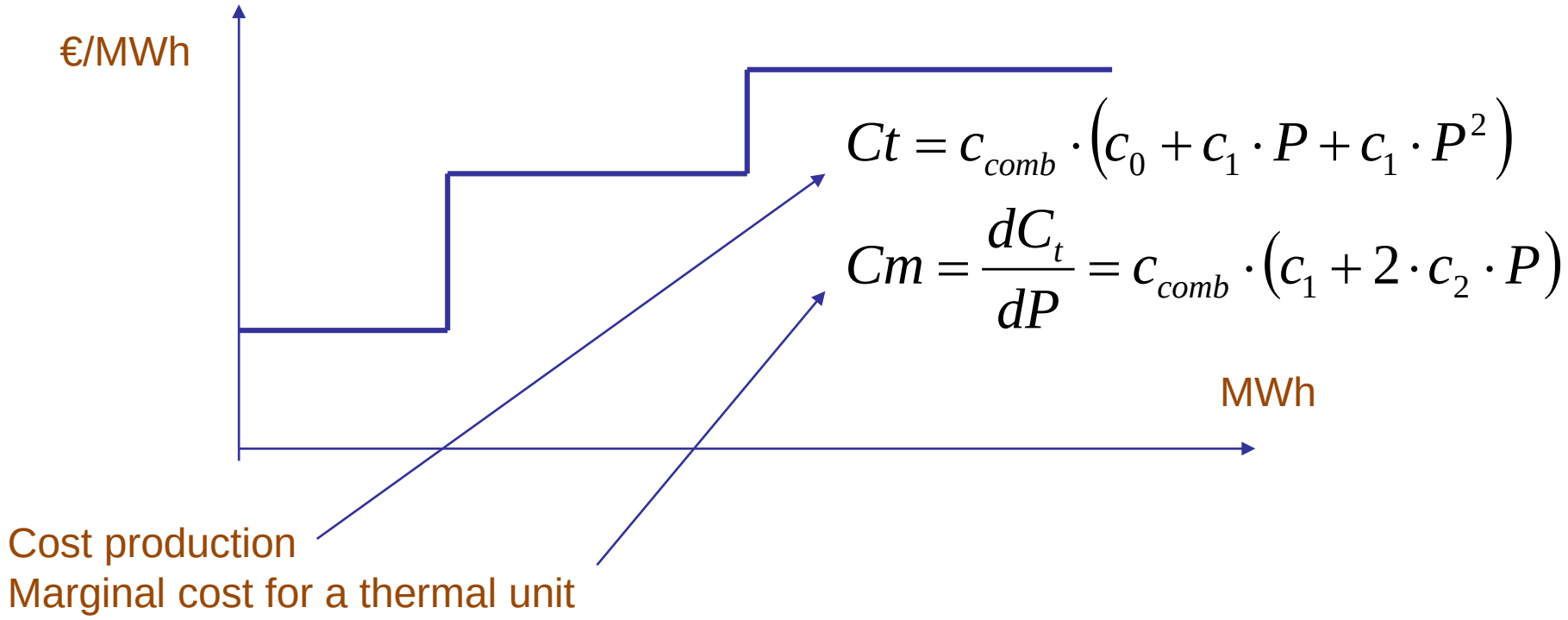


The PX auctions

- The day-ahead market is 24 separate double auctions, one for each hour
- These auctions operate considering transmission constrains
  - Nodal model or
  - Zonal model

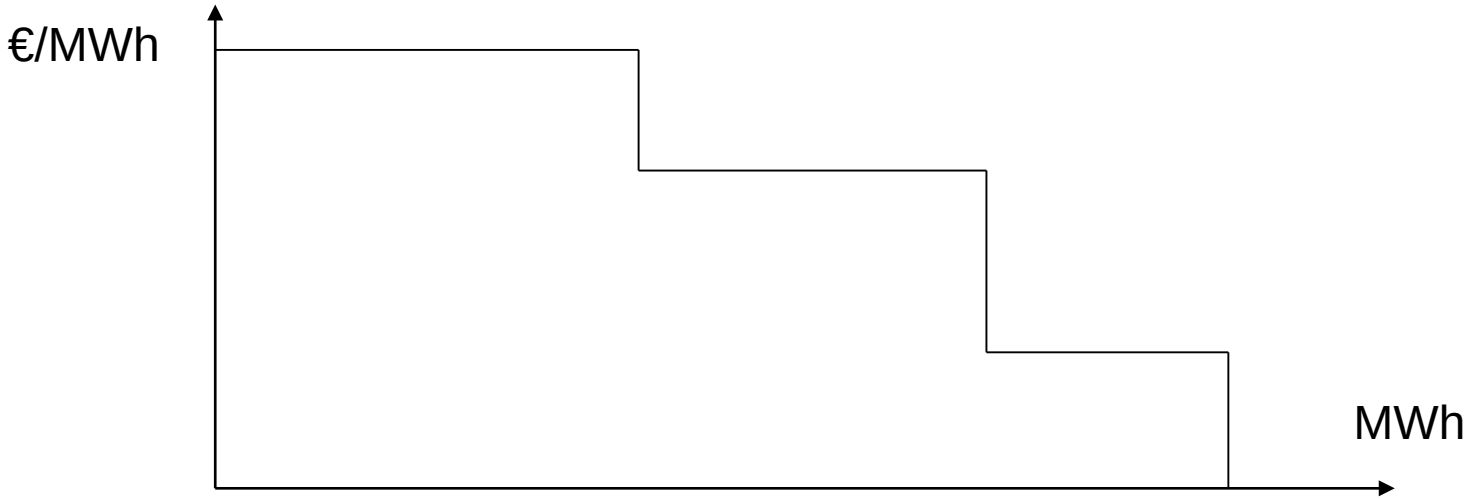
Seller's bid format

- Each bid is specified as a piece-wise linear curve
- Bid must be have non-negative slope



Buyer's offer format

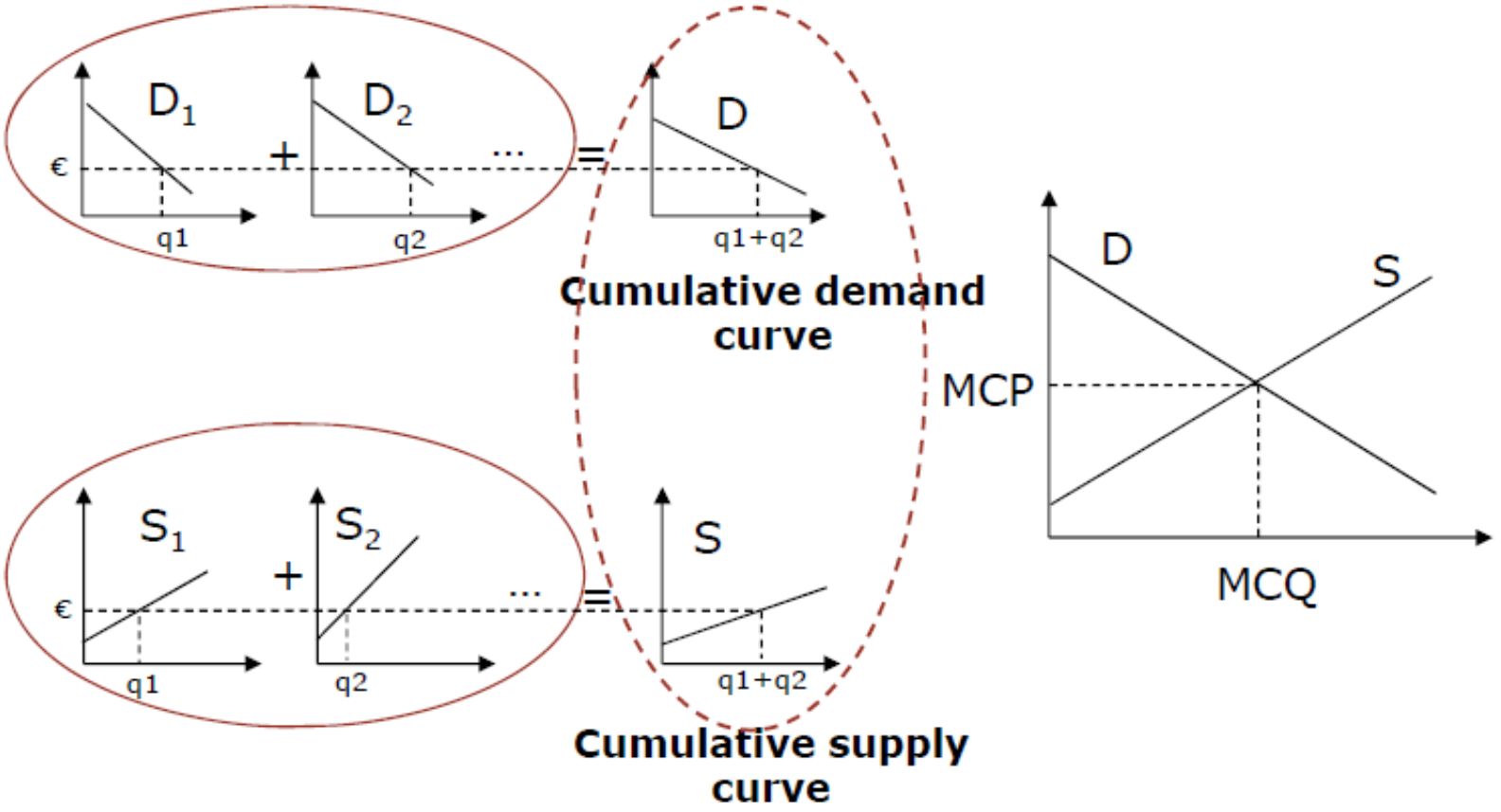
- Each bid is specified as a piece-wise linear curve
- Bid must have a non positive slope



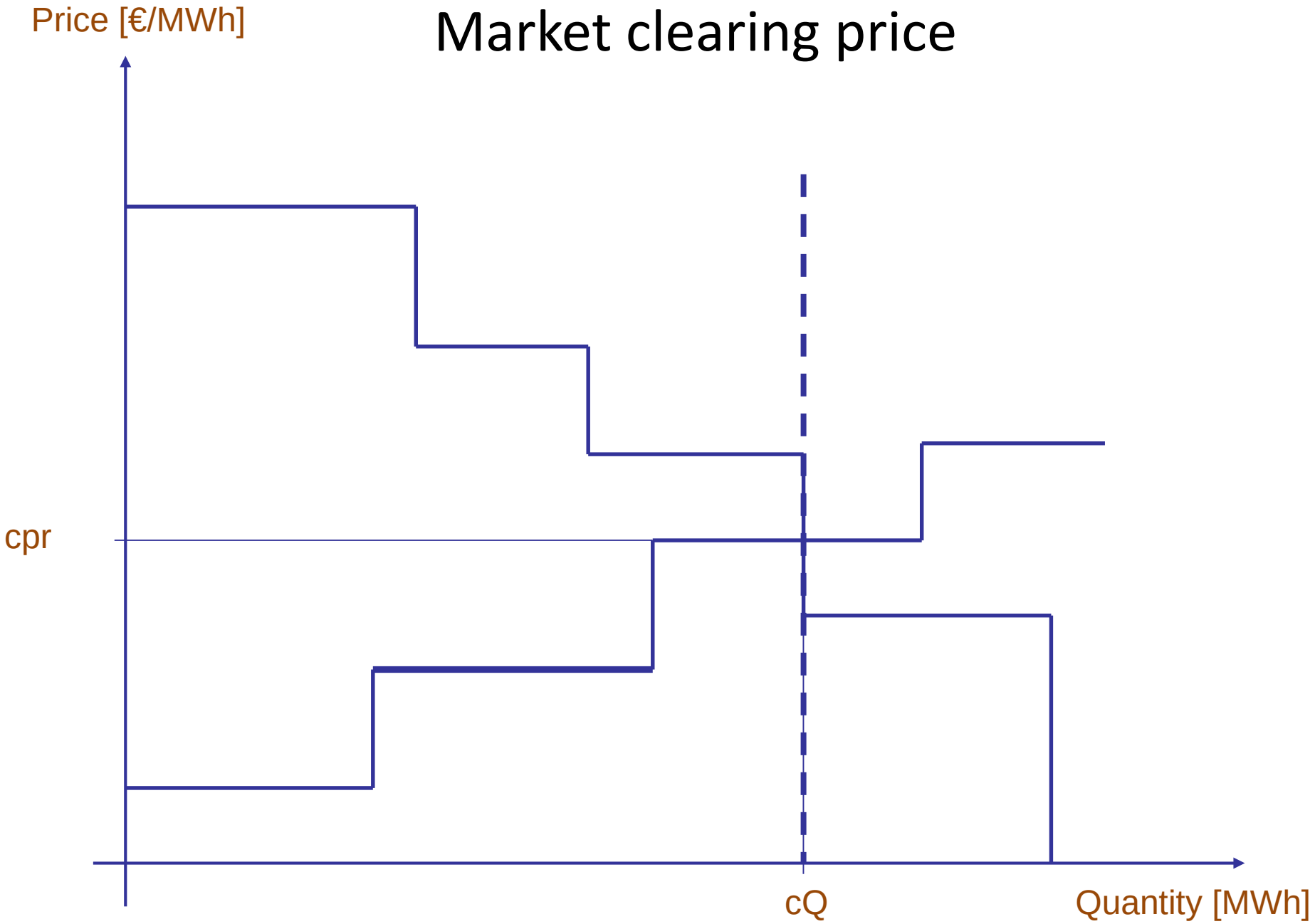
Market clearing price

- For each hour, the PX builds the hourly supply curve, the hourly demand curve from all the bids and offers, respectively
- The hourly market clearing price (MCP) is the point of intersection of the two curves
- The hourly generation schedules are established after the determination of the MCP
- All the supply bids with price equal or lower than the corresponding clearing price are accepted
- All the demand bids with price equal or higher than the clearing price accepted.

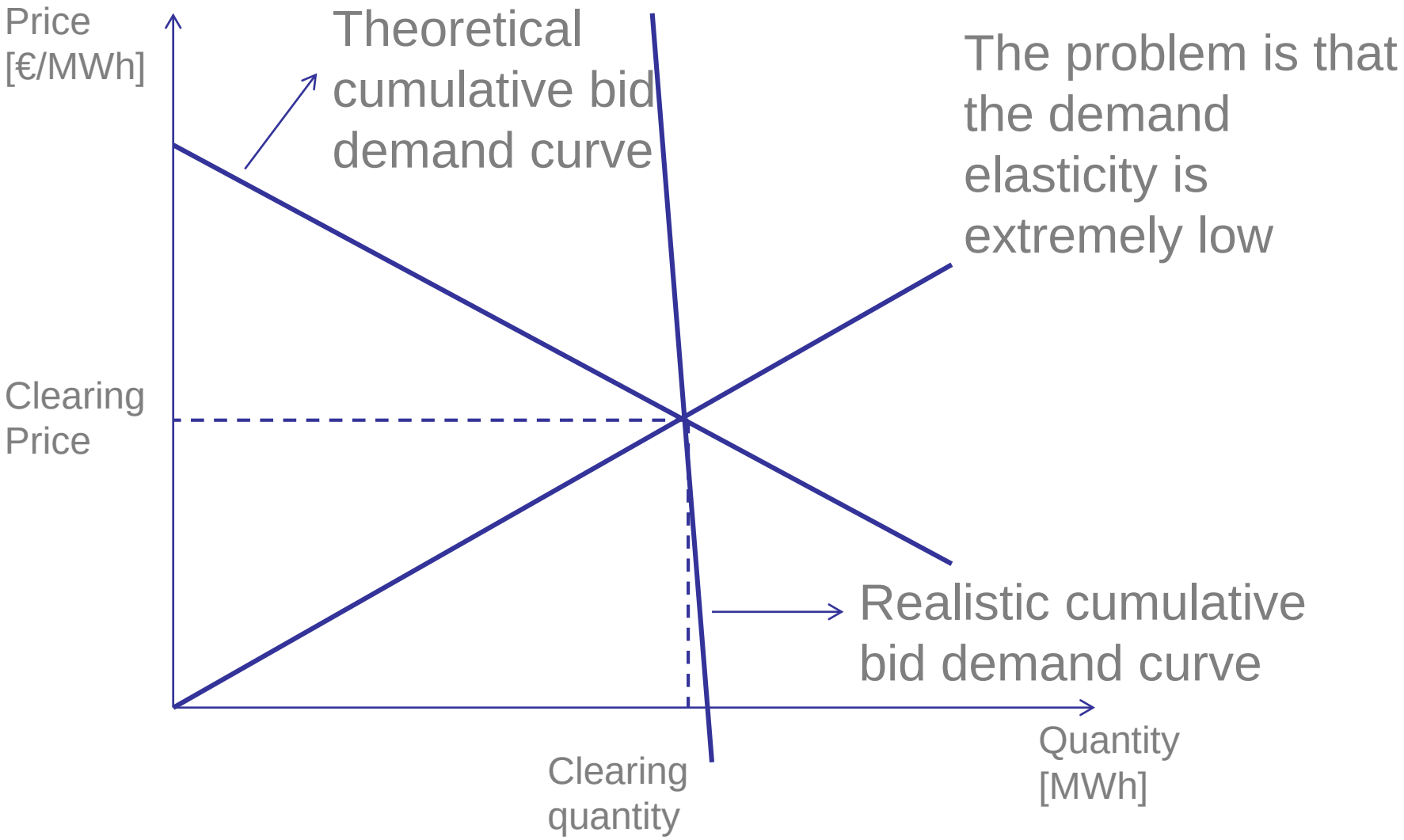
Market clearing price



Market clearing price



Demand bidding



Electricity pool

- Standardized contracts (i.e. time of delivery is one hour of the following day)
- Prices and quantities: maximum transparency
- Participants: anonymous
- Payment guaranteed (on the part of the clearing house)
- Most common pricing rule: uniform price auction
- Every seller and buyer with an accepted bid receives or pays the same price
- Marginal System Price, price indicated in the last accepted supply bid
- Less common pricing rule: pay as bid

Day-ahead market clearing

- Economic dispatch: unconstrained market clearing

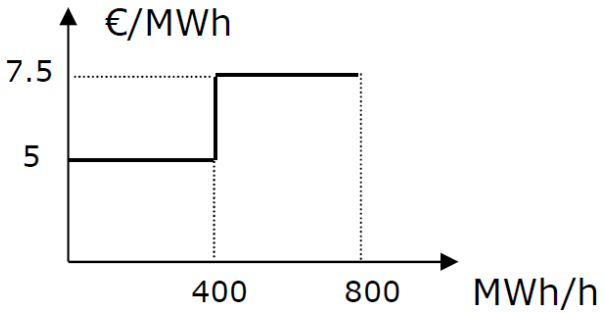
Day-ahead market clearing

- Hypotheses:
  - No transmission constraints
  - Perfectly competitive market:
    - Seller offers represent marginal costs of generation
    - Buyer bids represent marginal value of energy purchased
- MO clears the market: finds price(s) and quantities (i.e. successful offers and bids)
- Criterion: economic dispatch
  - Less costly generators first
  - Consumers with higer WTP first
- Mathematically
  - Constrained optimization problem
  - Economic objective: welfare maximization

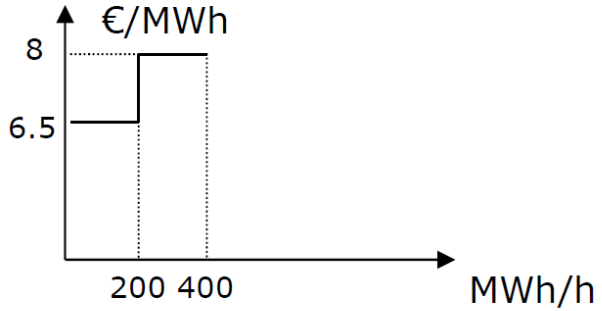
Example

Example

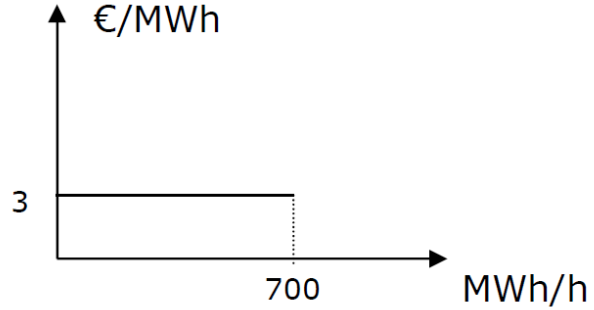
S1



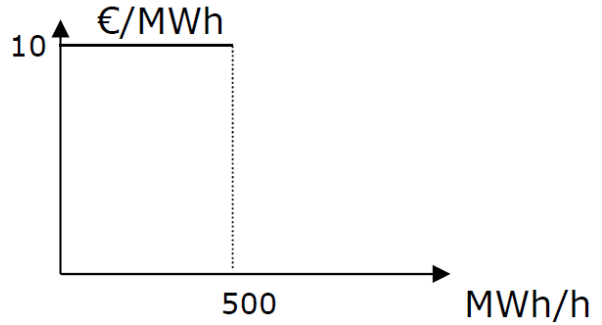
S2



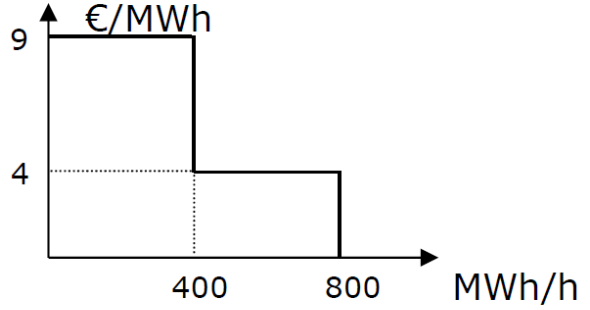
S3



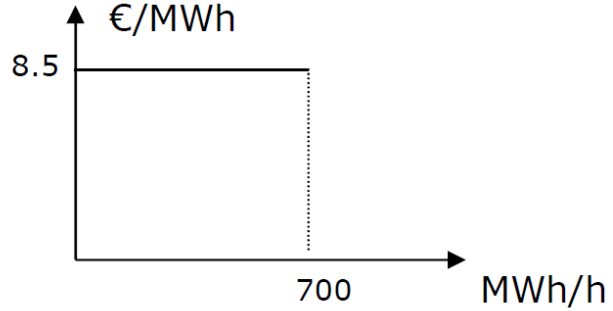
D1



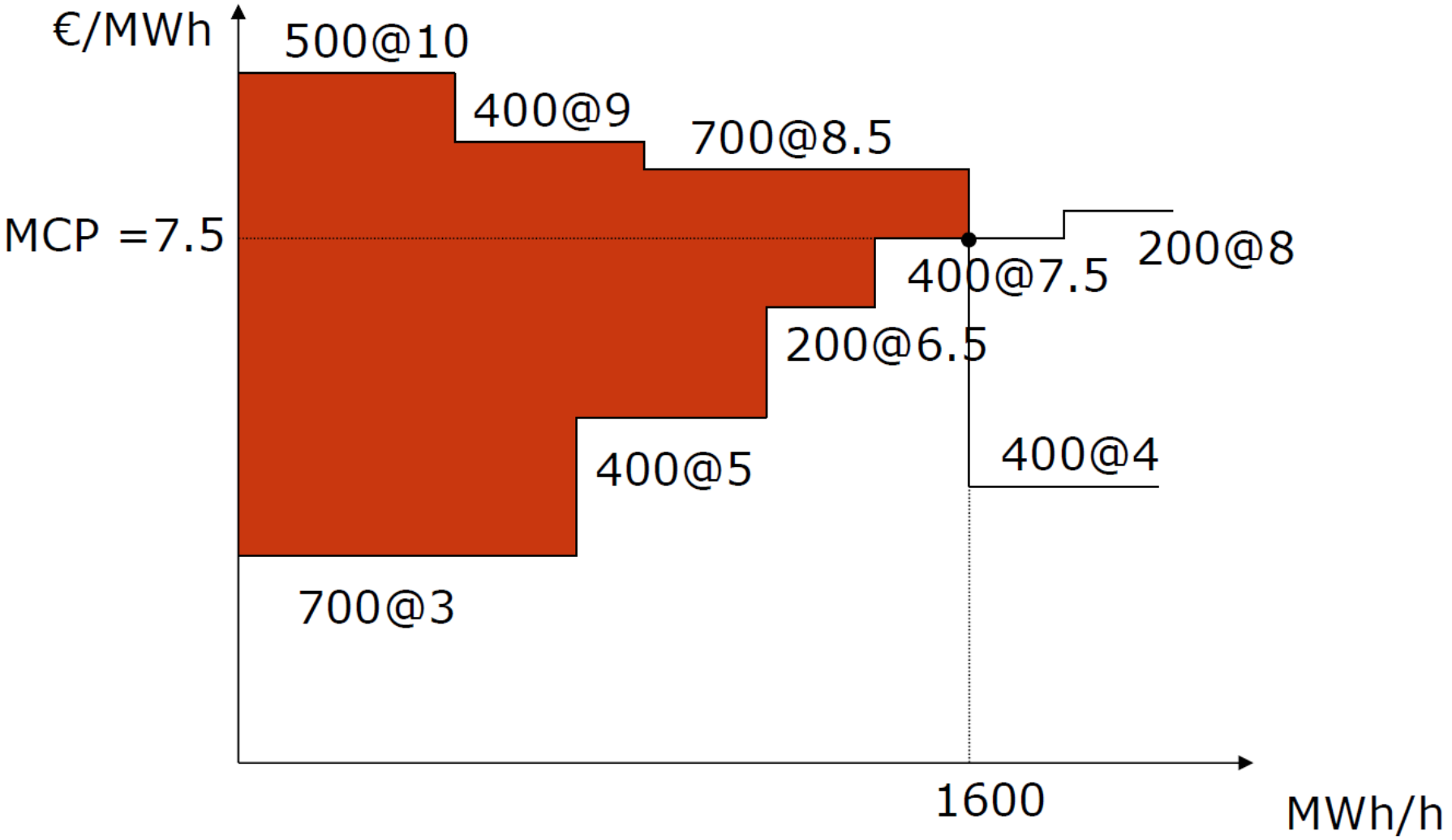
D2



D3



Example: the cumulative curves



Revenues and payments

Operator	**Accepted quantity [MWh]**	**Out of merit [MWh]**	Revenues [€]	Payments [€]
S1	700	100	5250	-
S2	200	200	1500	-
S3	700	0	5250	-
D1	500	0	-	3750
D2	400	400	-	3000
D3	700	0	-	5250
Total	1600	-	12000	12000

The market model

- Unconstrained market clearing

$$\underset{P_{Si},P_{Dj}}{max}\ W = \sum_{j=1}^{M} D_j\left(P_{Dj}\right) - \sum_{j=1}^{N} C_i\left(P_{Si}\right)$$

s.t.

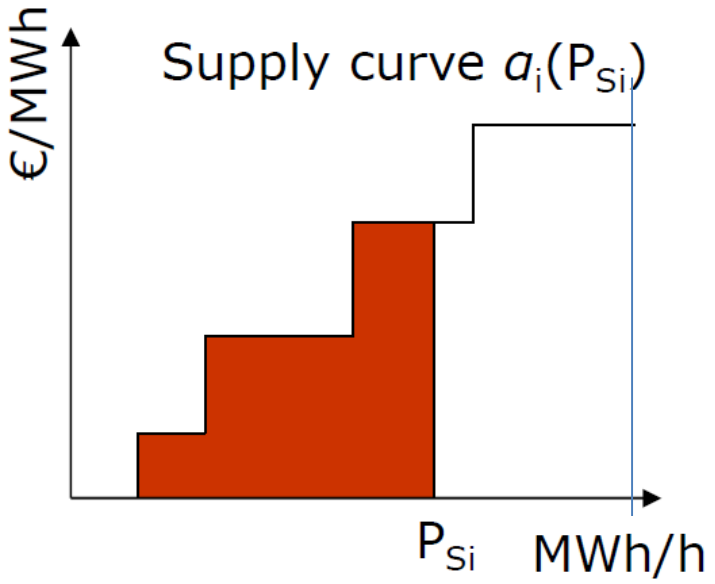
$$\sum_{j=1}^{M} P_{Dj} - \sum_{j=1}^{N} P_{Si} = 0$$

$$\underline{P_{Si}} \le P_{Si} \le \overline{P_{Si}} \qquad \forall i$$

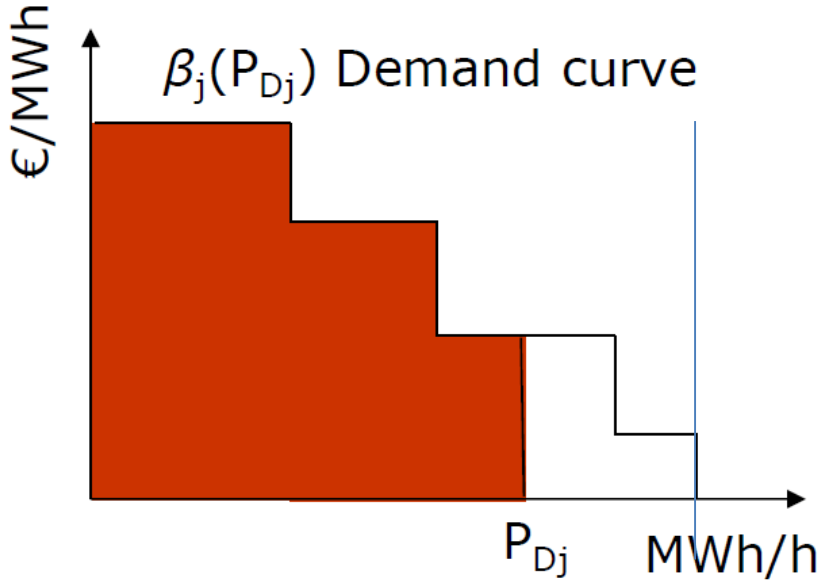
$$\underline{P_{Dj}} \le P_{Dj} \le \overline{P_{Dj}} \qquad \forall j$$

The meaning of the OF

Production cost (variable)



Consumer value



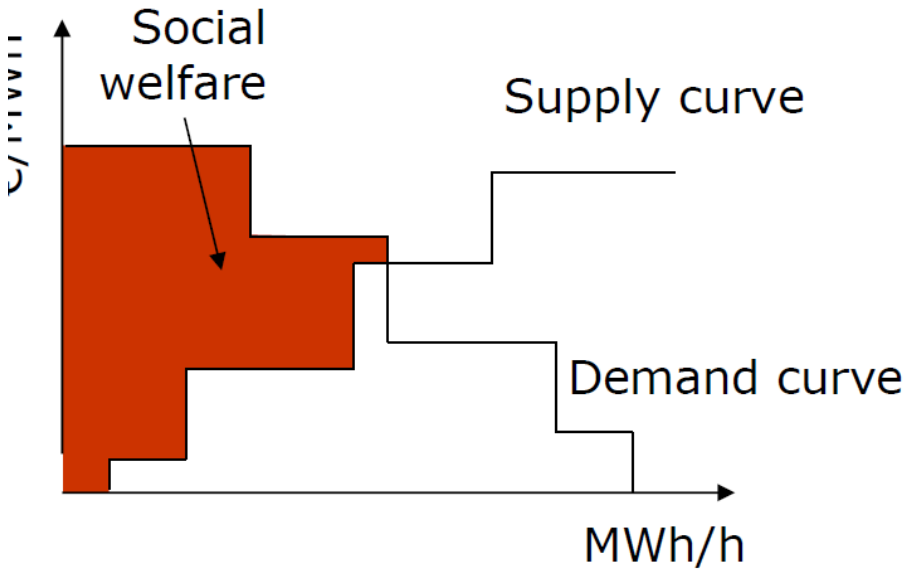
$$C_i(P_{Si}) = \sum_{k=1}^{Ns} \alpha_{i,k} P_{Si,k} = \int_0^{\overline{P_{Si}}} \alpha_i(P_{Si}) dP_{Si}$$

$$B_j(P_{Dj}) = \sum_{k=1}^{Nd} \beta_{j,k} P_{Dj,k} = \int_0^{\overline{P_{Di}}} \beta_i(P_{Di}) dP_{Di}$$

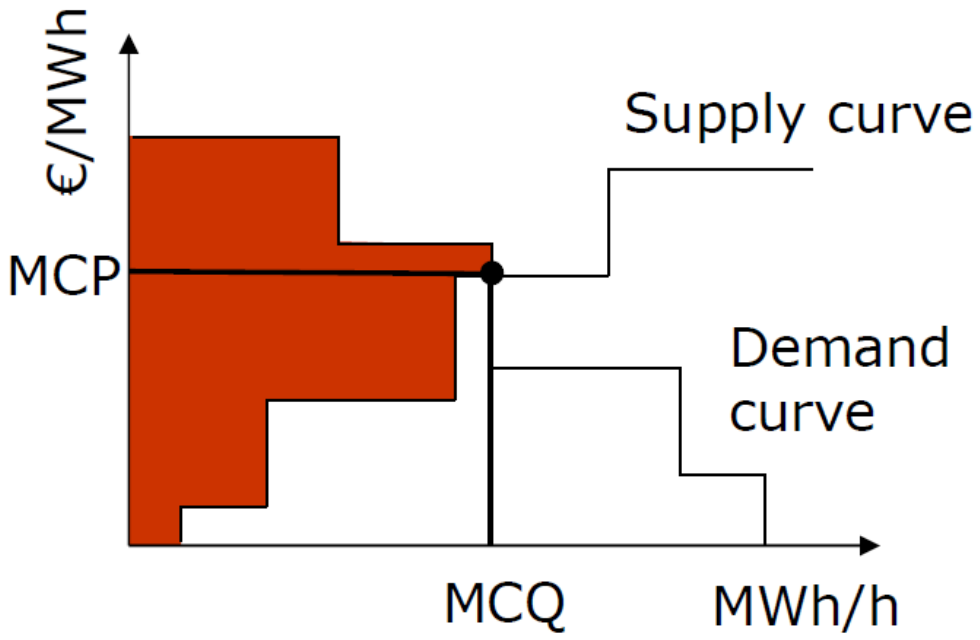
The OF is the maximization of the Social welfare

- Social welfare (red area): total benefit of the buyers minus total cost of the sellers

$$W = \sum_{j=1}^{M} D_j(P_{Dj}) - \sum_{j=1}^{N} C_i(P_{Si})$$



Market Clearing Price (MCP)

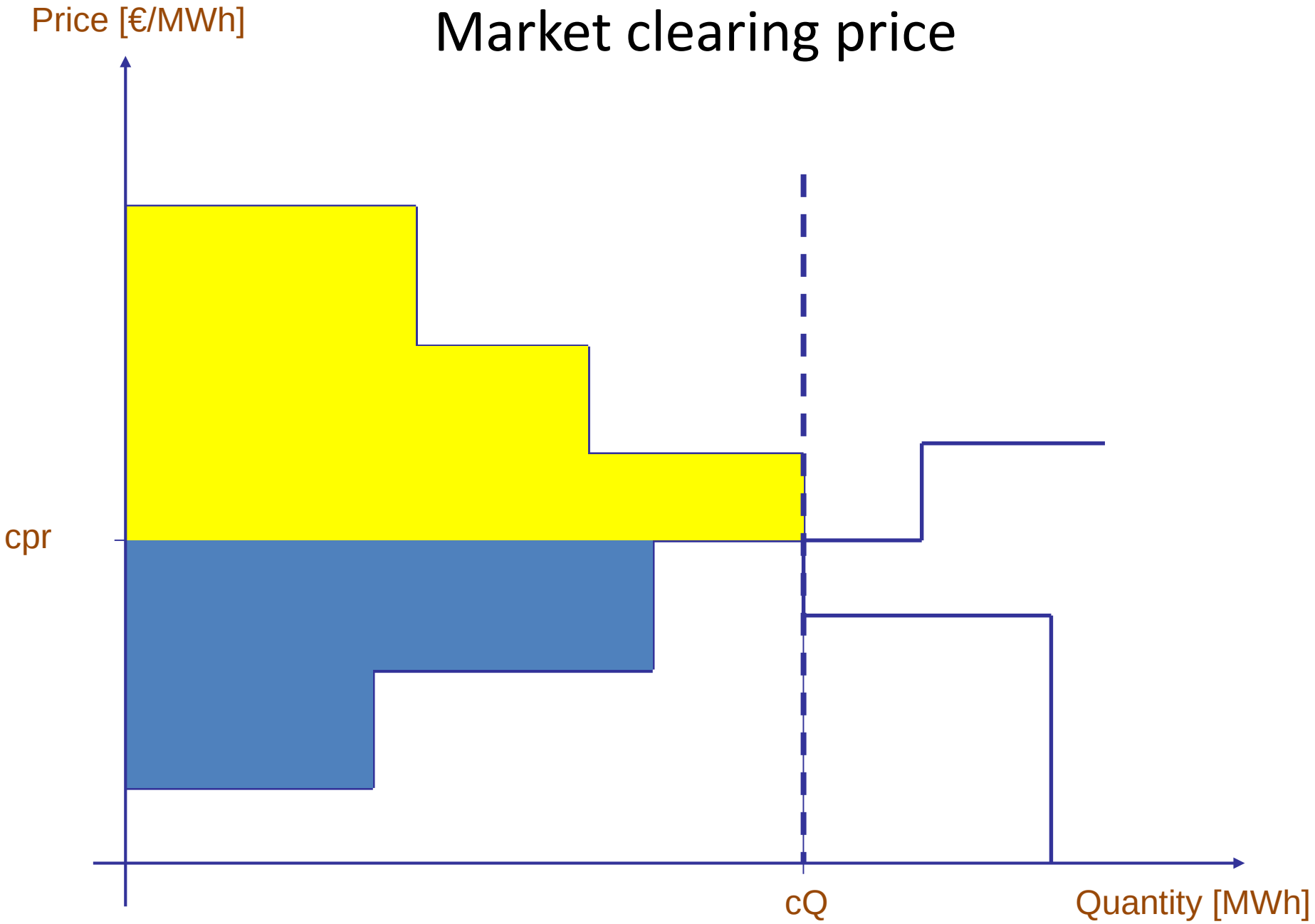


- MCP: change in social welfare for a unit change in the market clearing quantity
- Each seller receive MCP and each buyer pays MCP
- The MCP is different from the offer/bid of nearly every player

The Social welfare

- It is given by the sum of
  - the Producer Surplus and
  - the Consumer Surplus

Market clearing price



Producer Surplus

- For each seller *i* variable profit (surplus) is the difference between revenues (accepted quantity x MCP) and the supply curve

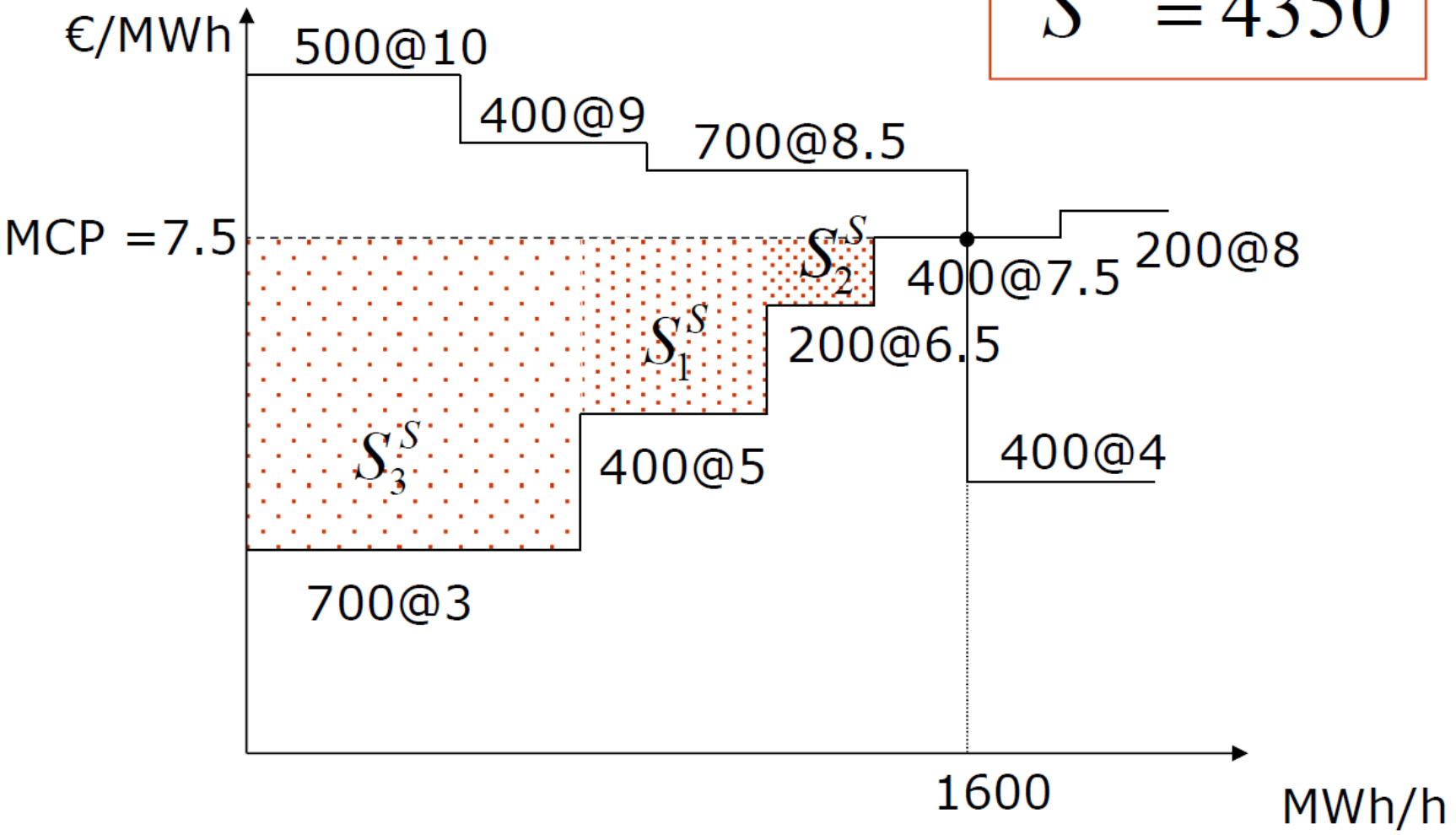
$$S_i^S = MCP \cdot P_{Si} - C_i(P_{Si})$$

- Total producers' surplus:

$$S^s = \sum_{i=1}^{N} S_i^S$$

Producer Surplus

$$S^S = 4350$$



Demand Surplus

- For each buyer *j* surplus measures the difference between the demand curve and the payments (accepted quantity x MCP):

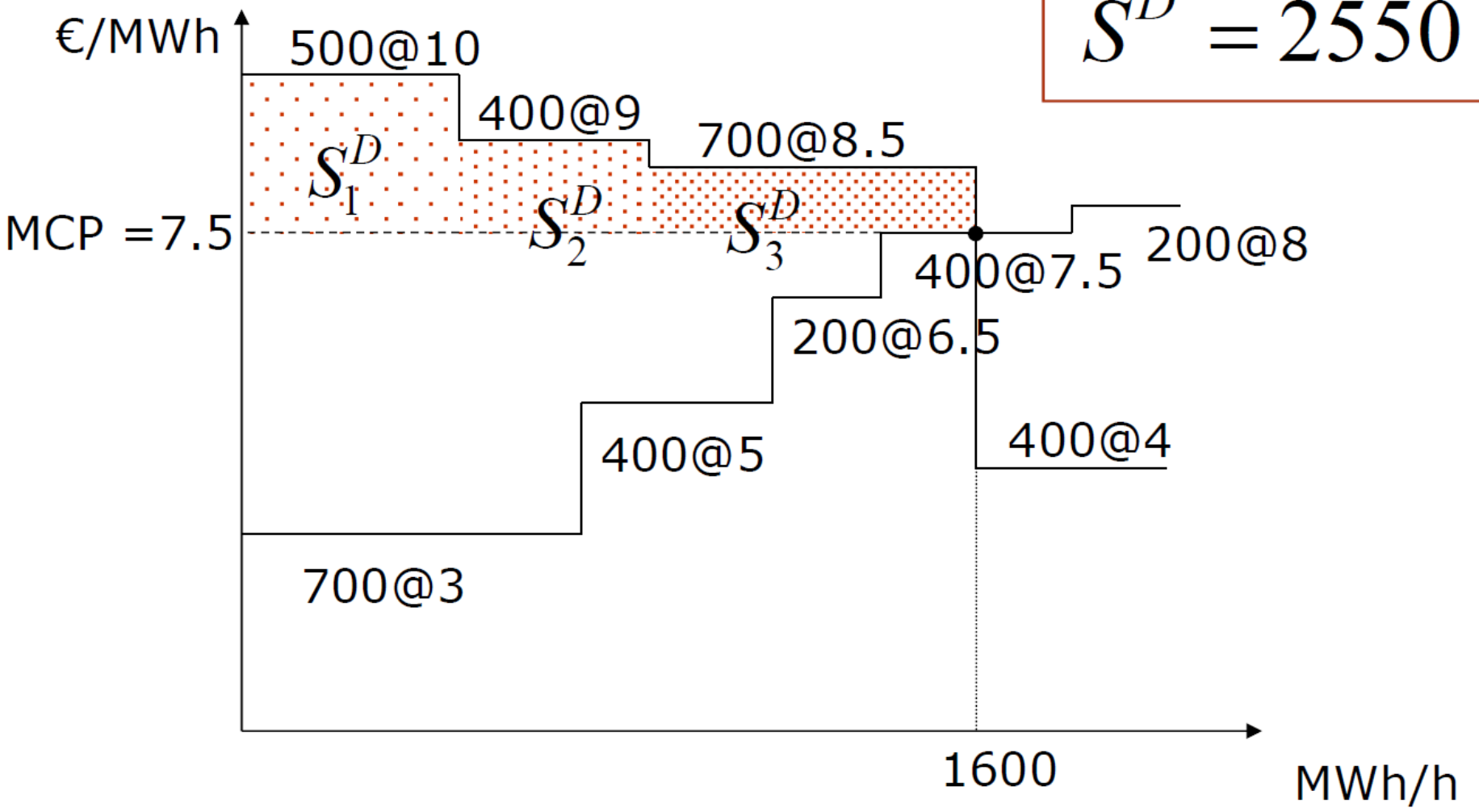
$$S_j^D = D_j\left(P_{Dj}\right) - MCP \cdot P_{Dj}$$

- Total consumers' surplus

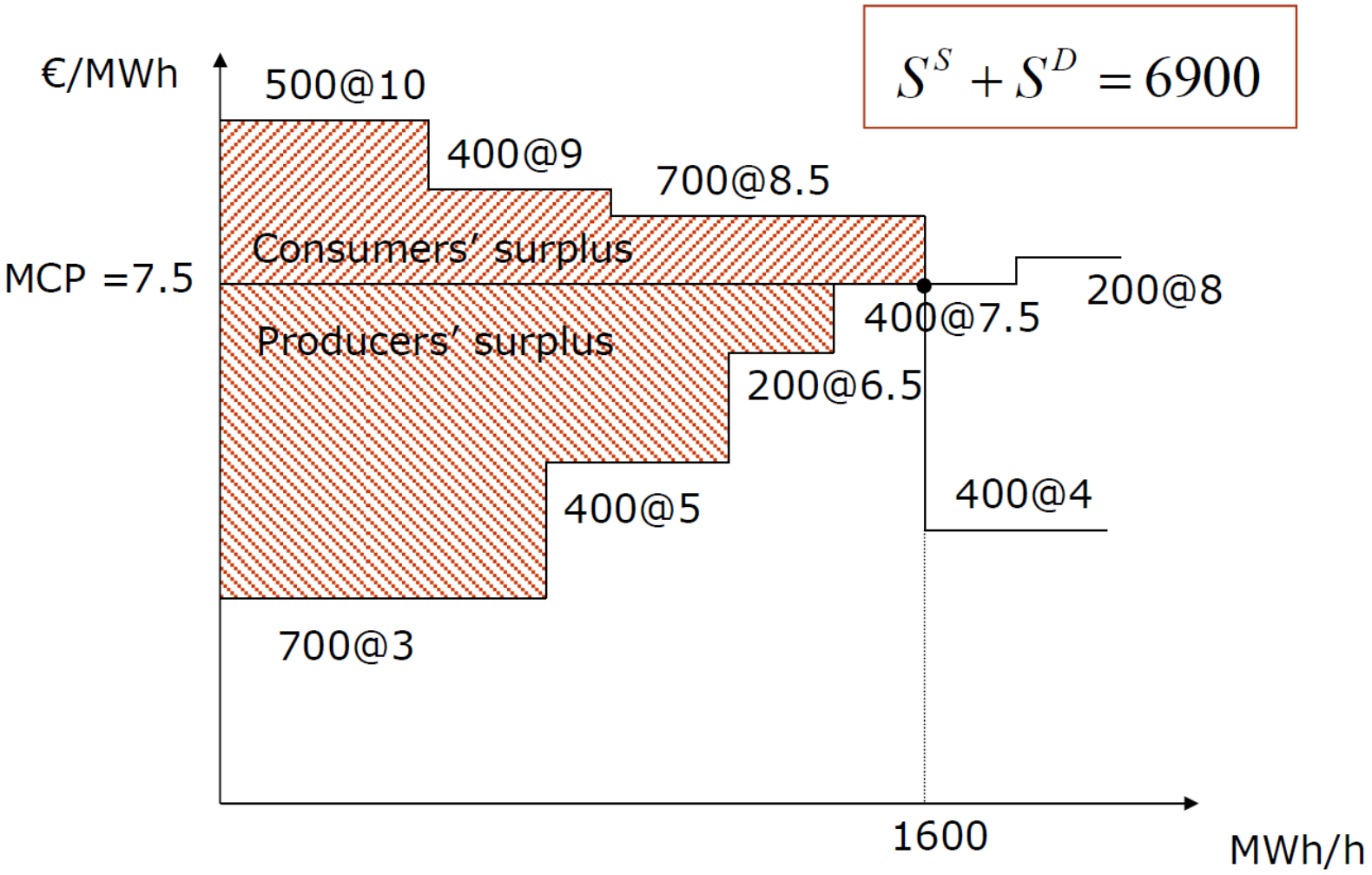
$$S^s = \sum_{j=1}^{M} S_j^S$$

Producer Surplus

$$S^D = 2550$$



The social welfare



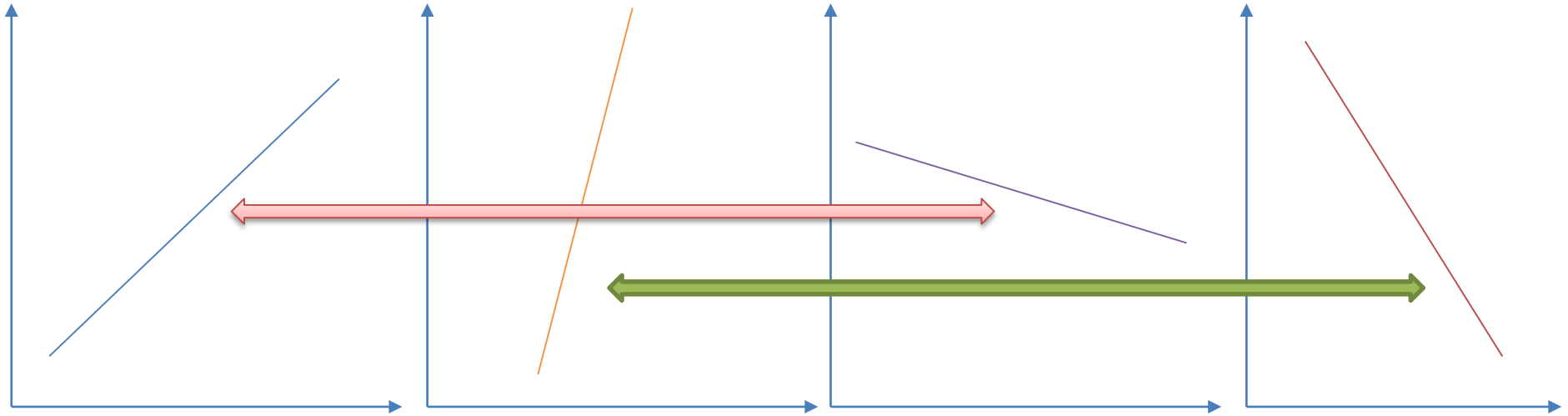
The bilateral paradigm

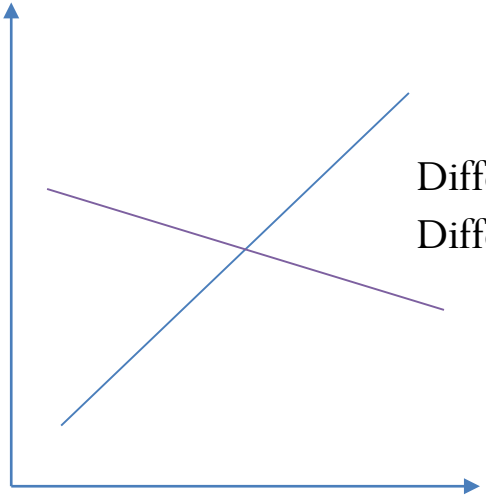
The bilateral paradigm

- Buyers and sellers define transactions autonomously and privately
- The TSO is notified and allows bilateral transactions, s.t. network constraints
- Non standardized contracts
- Stipulated years, months, day(s) ahead of delivery
- Continuous trading
- No transparency wrt other operators
- Operators are not anonymous
- Counterparty risk

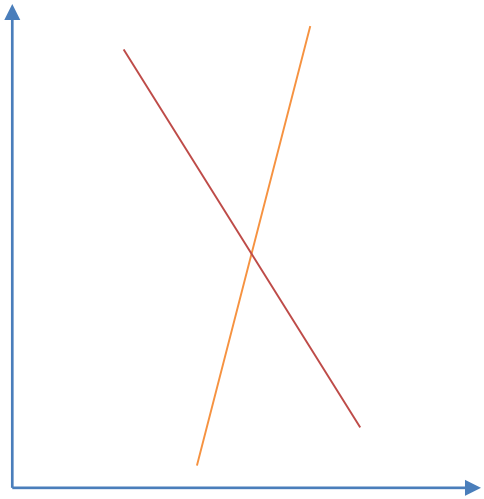
The bilateral paradigm

The bilateral paradigm





Different prices P_1, P_2…
Different quantities Q_1, Q_2, …



The real electricity market

- Pool market model and bilateral market model coexist in the same liberalised market
- The seller can choose where to sell energy: in the pool market or by bilateral market
- The buyer can choose where to buy energy: in the pool market or by bilateral market
- Generally the base load energy is exchange via bilateral contract and the (variable) unpredictable demand is traded in the pool market

The real electricity market

- Pool market model and bilateral market model coexist in the same liberalised market
- The seller can choose where to sell energy: in the pool market or by bilateral market
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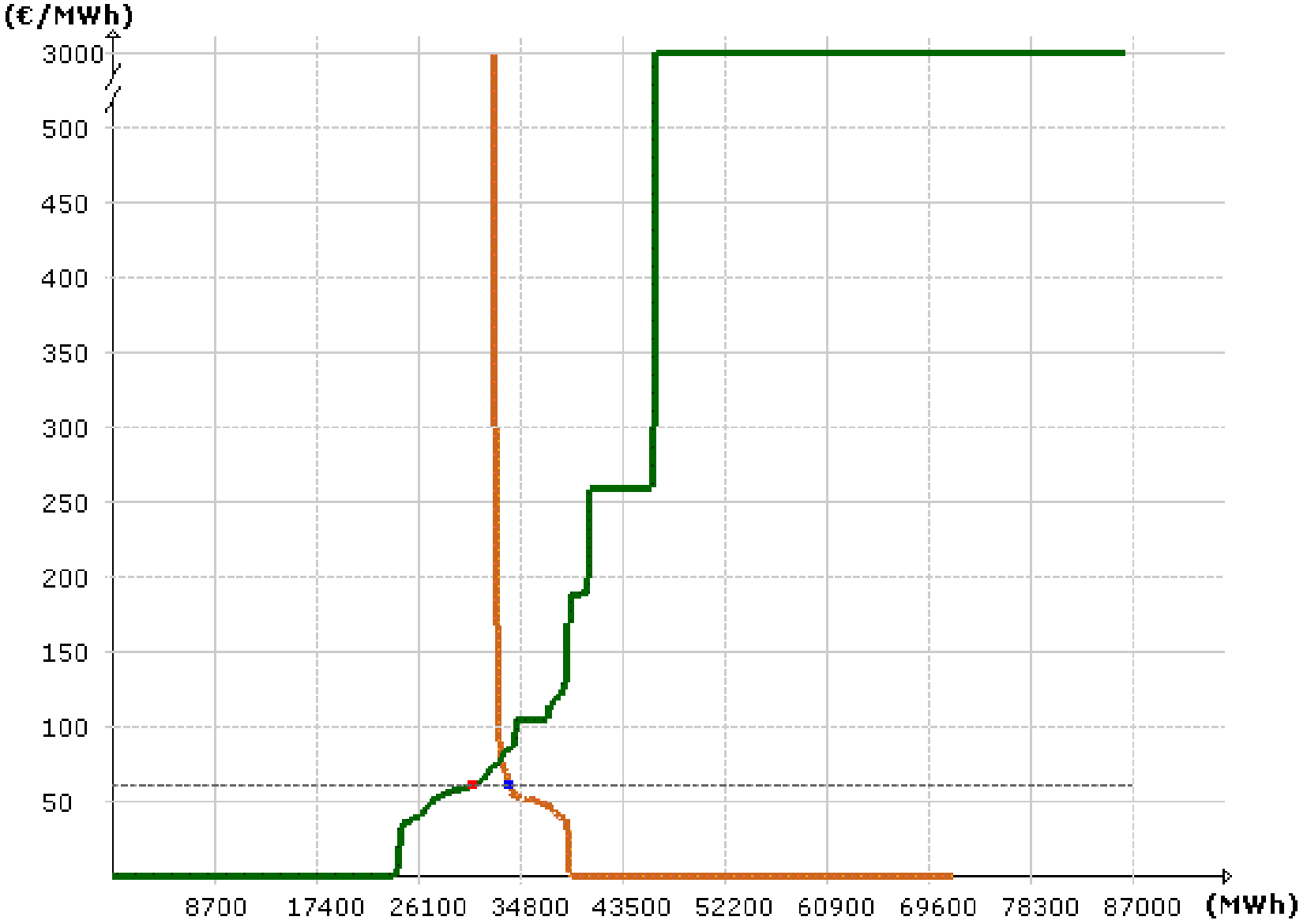
- Generally the base load energy is exchange via bilateral contract and the (variable) unpredictable demand is traded in the pool market

The real electricity market

- Generally, bilateral contracts take precedence over energy traded in the pool market
- The pool define the clear market solution
  - in the clearing process it is necessary to take into account the energy traded by bilateral contracts
  - The bilateral contract are represented in pool market in the following way:
    - The sell energy is represented with a bid with price equal to zero
    - The bought energy is represented with a bid with a very high price
    - In this way, the precedence of these contract in the clearing process is guaranteed
    - The energy traded via bilateral contracts do not receive the clearing price

Market Zone: CNOR; CSUD; NORD; SARD; AUST; CORS; COAC; FRAN; MFTV; SLOV; SVIZ; BS

Date: 29/10/2014 **Hour:** 12



An important question

- If the spot price reflect only the marginal cost of the last generator selected, how do generators get paid for their investment costs?
  - Generators with lower running cost will make a profit from the market prices set at the highest bid. This is a contribution to the investment cost
  - The prices need to rise at the peak times to provide enough to cover the investment of the last generator on the system. It can be shown that all the generators need this amount to recover their investment costs

An important question

- Last accepted bid: marginal bid
  - Covers variable costs of production
- Other accepted bids: infra-marginal bids
  - cover The fCover variable costs of production and obtain an infra-marginal rent per MWh equal to the difference between the MCP and the marginal cost of production:
  - ixed costs are covered
- Bids out of merit: extra-marginal bids
  - No production costs
  - No revenues: cannot recover fixed costs