Power Market Operations

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Source: Chapter 3.2, Papavasiliou [1]

Outline

- Exchanges and pools
- Uniform and pay-as-bid auctions
- Electricity market blueprint
- Example: California and Central Western Europe

Exchanges and pools

The motivation for markets

- Information: each agent uses only private information
- Short-run efficiency (Adam Smith's "invisible hand"): profit-maximizing agents behave optimally from a global point of view if "the price is right"
- Long-run efficiency: correct investment incentives

Degree of centralization

Bilateral (least centralized) → Exchange → Pool (most centralized)

- **Bilateral trade**: traders exchange in pairs
- **Exchanges**: traders submit simple bids to auctions with simple rules
- **Pools**: traders submit multi-part bids to auctions with complex rules

Can electricity be traded bilaterally in real time?

Example: exchange versus pool

Consider a generator with startup cost of $2400, capacity of 10 MW and fuel cost of 20 $/MWh who wants to sell energy for 24 hours

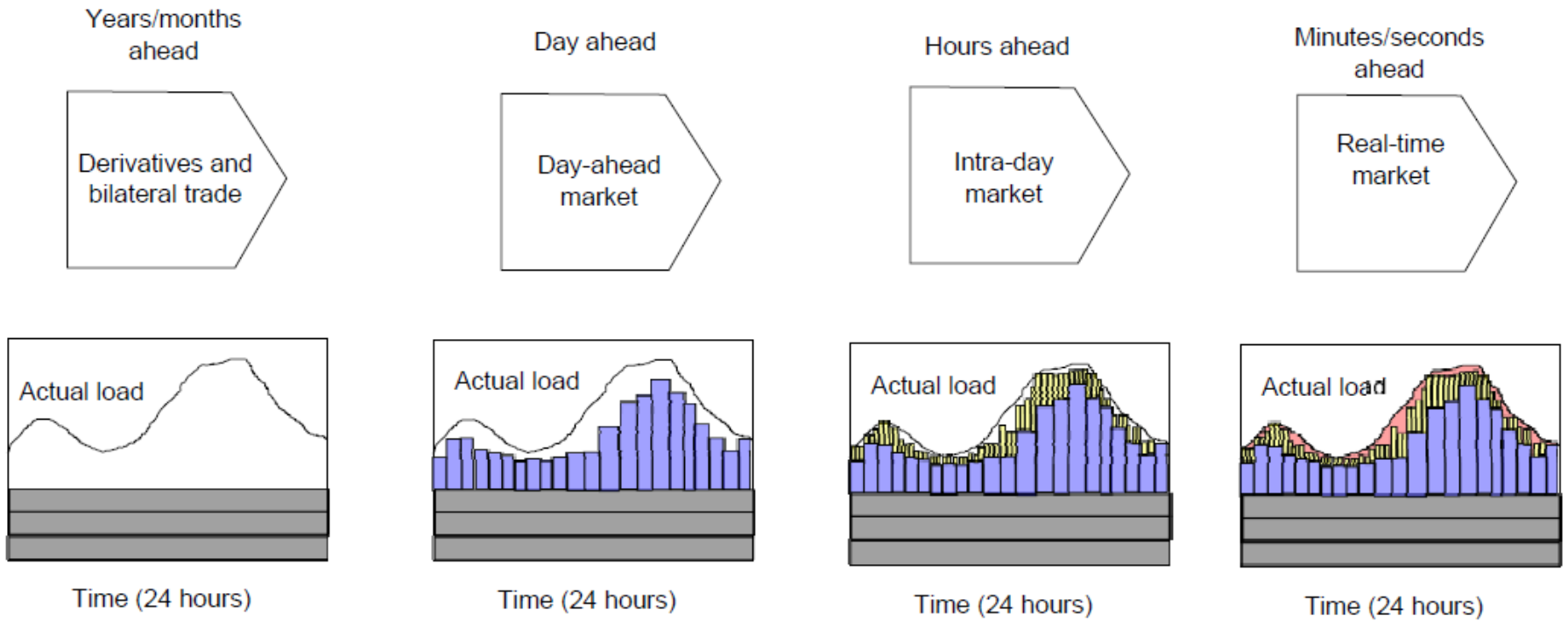
- Exchange: at least how much should the generator bid in order not to suffer financial losses?
- Pool profit given energy price P:

$$\max\big((P-20)\cdot 10\cdot 24-2400,0\big)\,€$$

- Pool side payment:

$$\max(2400-(P-20)\cdot 10\cdot 24,0)\,€$$

Degree of centralization in different time frames



Uniform and pay-as-bid auctions

Uniform-price auctions

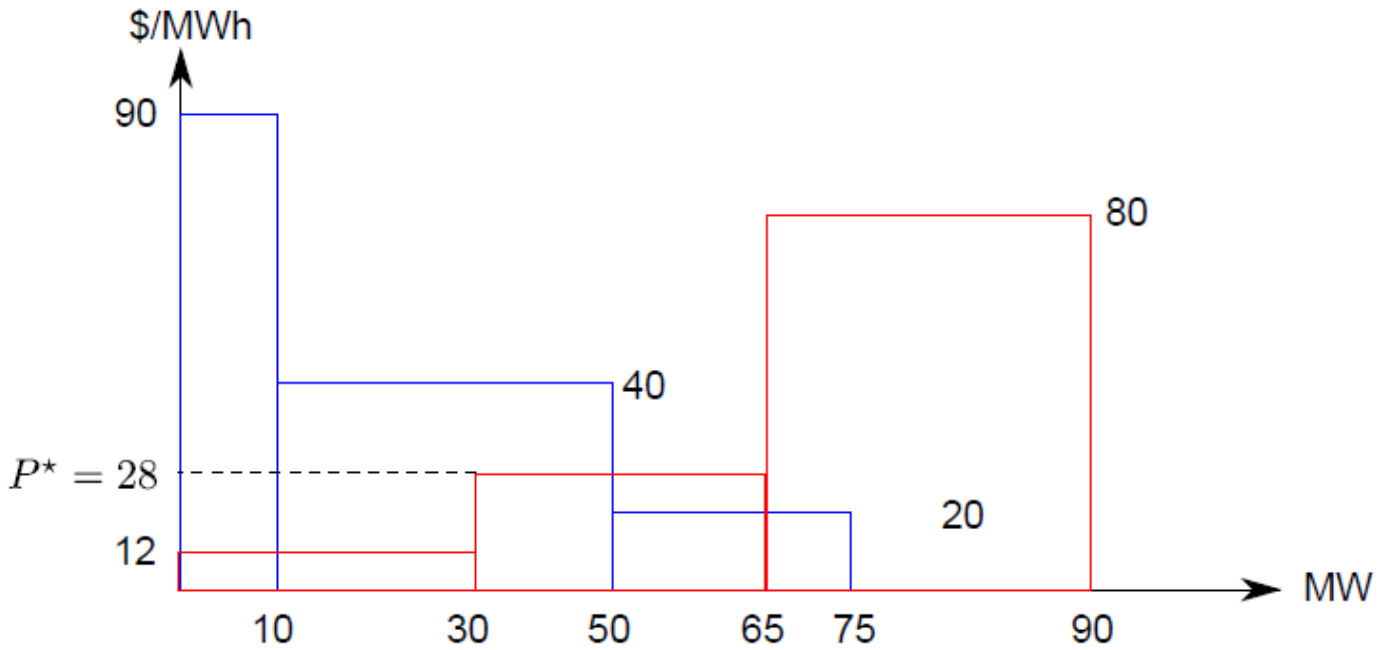
- Generator bids: price-quantity pairs (P, Q), representing price P at which producers are willing to produce quantity Q
- Consumer bids: price-quantity pairs (P, Q), representing price P consumers are willing to pay for quantity Q
- Obligations and payoffs:
  - Market clearing price P^*: intersection of supply and demand curves
  - *In the money* supply bids: produce and receive P^* €/MWh
  - *In the money* demand bids: consume and pay P^* €/MWh

Example

The following bids are submitted for *5-minute* power in a uniform price auction

- Producer 1: 30 MW at 12 $/MWh
- Producer 2: 35 MW at 28 $/MWh
- Producer 3: 25 MW στα 80 $/MWh
- Consumer 1: 10 MW at 90 $/MWh
- Consumer 2: 40 MW at 40 $/MWh
- Consumer 3: 25 MW at 20 $/MWh

- What is the uniform price?
- What is each producer's profit?
- What is each consumer's profit?
- How much surplus is left to the auctioneer?


$/MWh
90
80
40
$P^\star = 28$
20
12
MW
10
30
50
65
75
90

Second-price auctions

Auctions for selling one item

- Lowest bidder (supplier) paid for supplying the auctioned item
- Supplier is paid price bid by cheapest losing bidder

Induces truthful bidding

- Why would you want to understate cost?
- Why would you want to overstate cost?

William Vickrey: 1996 Nobel prize in economics

Example: second-price auction for commissioning a public construction project

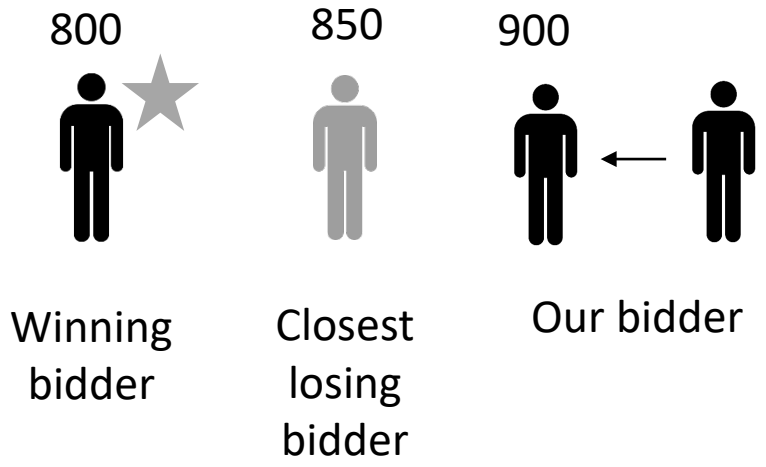
- Second-price auctions assign a project to the lowest-cost bidder, but pay the awardee the price that was offered by the second lowest-cost offer
- We claim that second-price auctions result in truthful offers
- Consider a potential supplier with a privately known cost of $1000

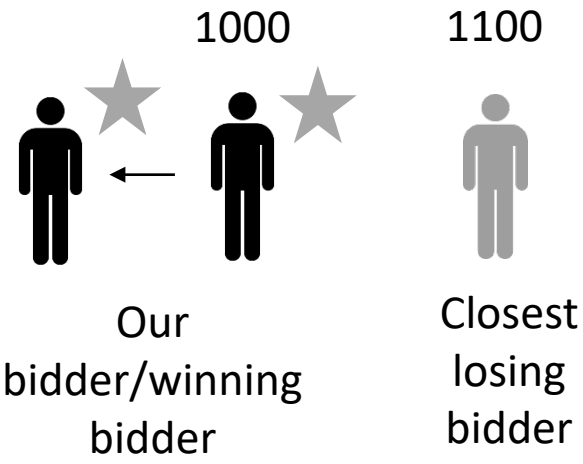
Proof strategy

- We analyze two cases
  - Under-bidding: the firm bids a cost that is lower than the actual one, e.g. $900
  - Over-bidding: the firm bids a cost that is higher than the actual one, e.g. $1100
- We want to show that both cases lead to the firm being worse off relative to truthful bidding. We can prove it consider two sub-cases for each case:
  - The state of the firm does not change (state being whether the firm wins the auction or not)
  - The state of the firm changes

Case 1: under-bid

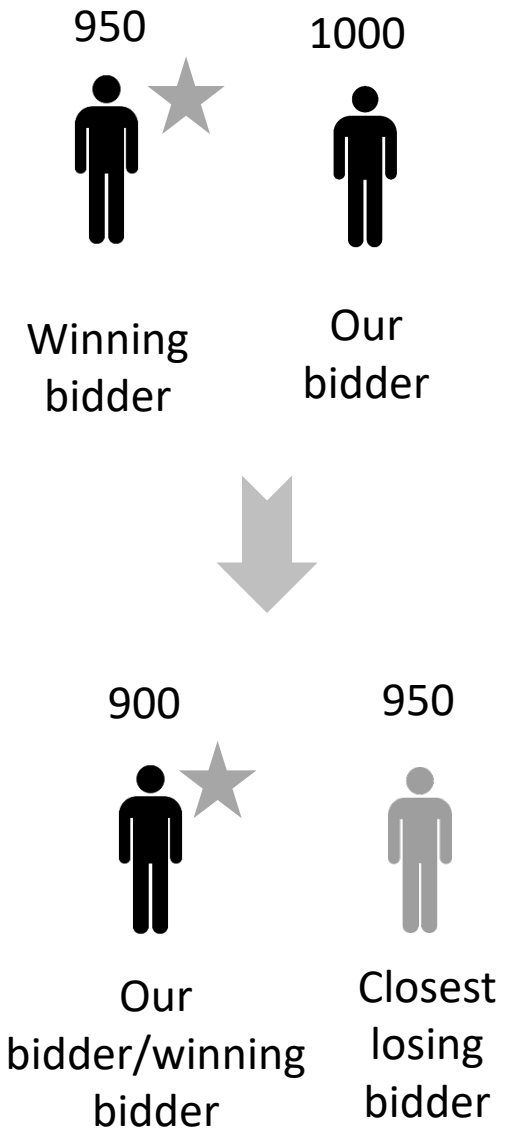
- Case 1.1: state of the firm does not change
  - If the firm changes its bid from \$1000 to \$900 and loses the auction, then its profit does not change
  - If the firm changes its bid from \$1000 to \$900 and still wins the auction, then its profit does not change because the price is determined by the 2nd lowest-cost **offer by design of the second-price auction**
- The payoff therefore does not change in case 1.1 when the firm under-bids





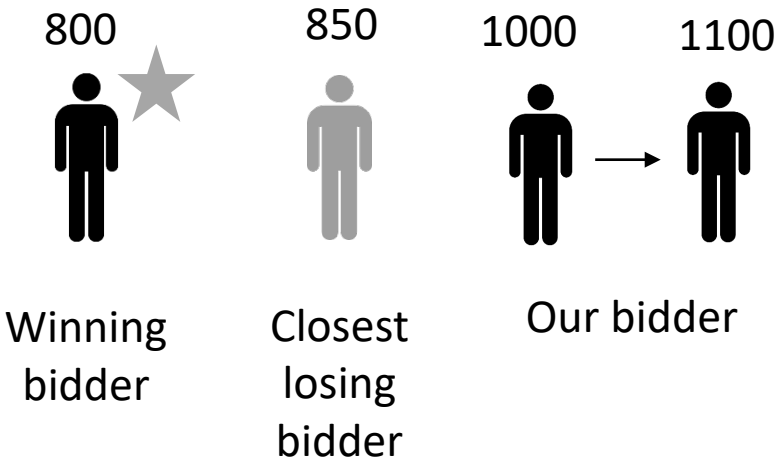
Case 1: under-bid

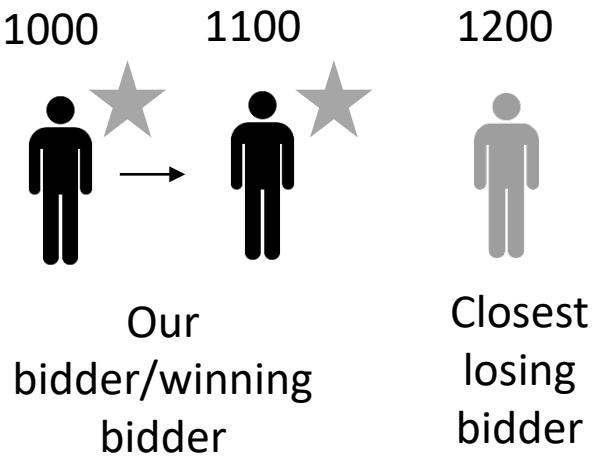
- Case 1.2: the state of the firm changes
  - If the firm changes its bid from $1000 to $900 and the firm ended up losing the auction instead of winning it, it is because there is another firm bidding less than $1000 which prevents our form from winning. But in this case the profit of the firm changes from 0 to something negative!
- Therefore in this case the profit changes, but becomes worse!



Case 2: over-bid

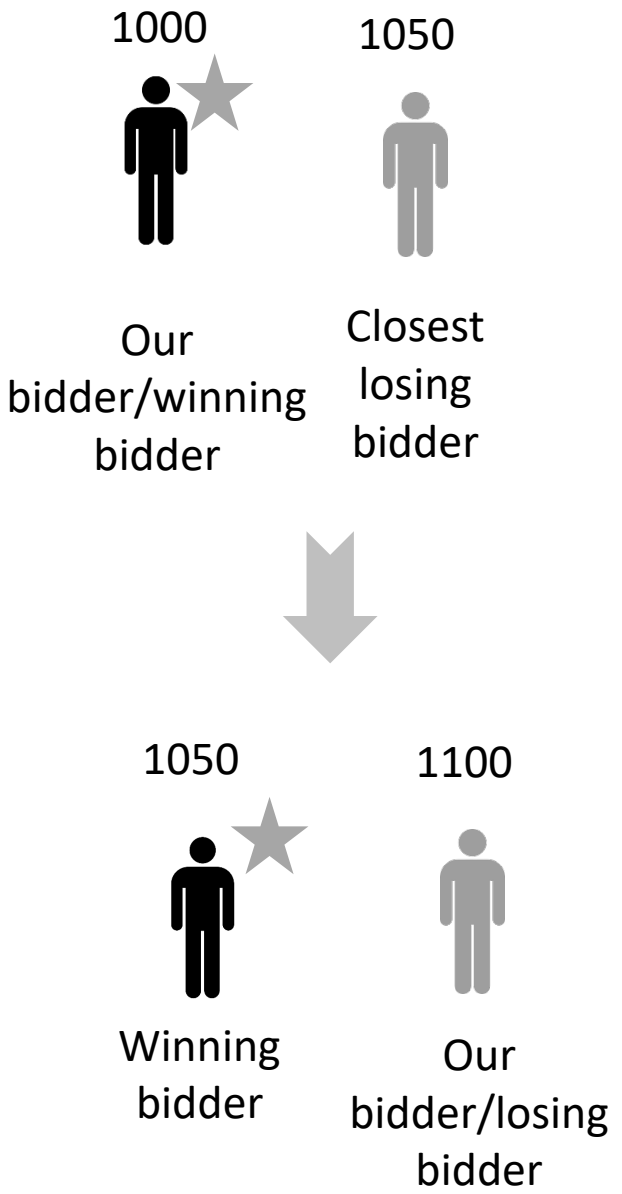
- Case 2.1: the state of the firm does not change
  - If the firm changes its bid from $1000 to $1100 and the firm still loses the auction, then the profit does not change
  - If the firm changes its bid from $1000 to $1100 and it still wins the auction, then the profit does not change because the price is set by the second lowest-cost offer **by design of the second-price auction**
- Therefore the profit does not change in case 2.1 when the firm over-bids





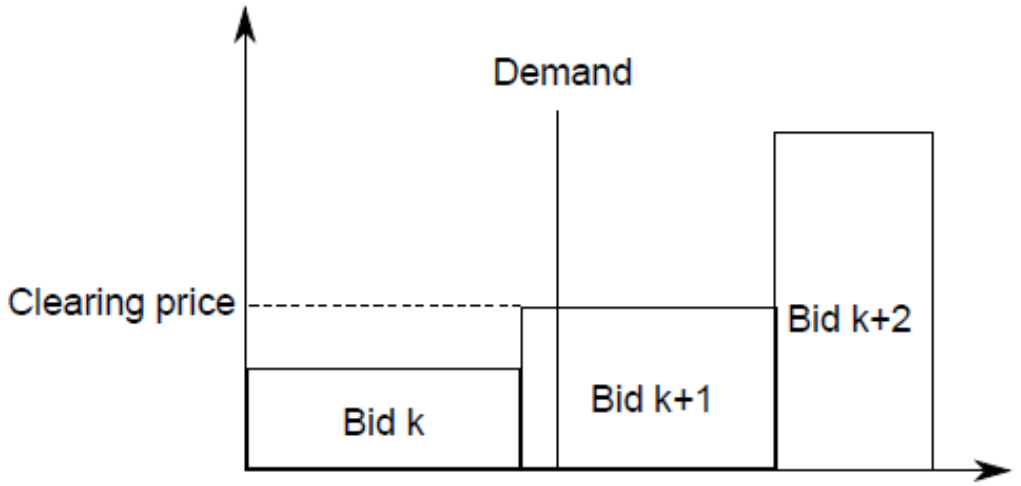
Case 2: over-bid

- Case 2.2: the state of the firm changes
  - If the firm changes its bid from $1000 to $1100 and the firm ends up losing the auction instead of winning it, it is because there is a competitor with an offer that exceeds $1000 which prevents the firm from winning. But in this case the profit of the firm changes from something positive to zero!
- Therefore in this case the profit changes, but becomes worse!

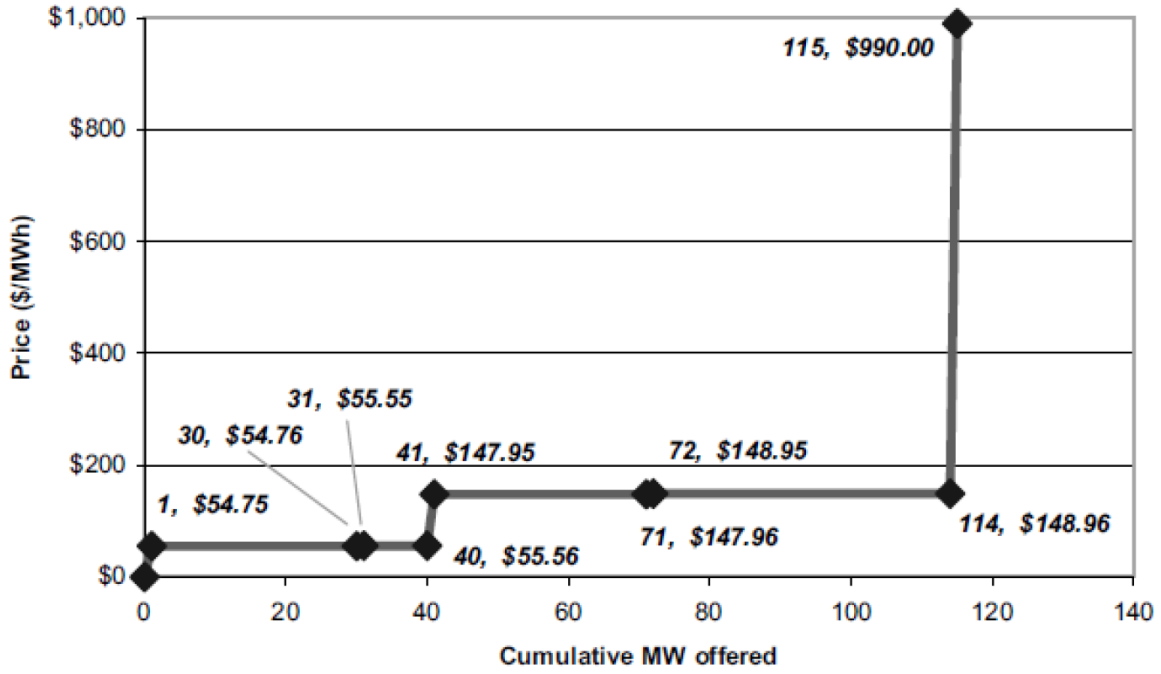


From second-price auctions to uniform-price auctions

Uniform prices are a natural generalization of second-price auctions to multiple items, "losing" bid is $k + 1$



Hockey stick bidding



Meanwhile, in Texas (February 24, 2013)

Pay-as-bid auction

Pay-as-bid pricing: Bids are accepted in order to maximize benefit from trade, each agent pays/receives the price they bid

Criticisms of uniform pricing

- Price volatility
- Hockey-stick bidding
- Unfair profit margins for infra-marginal suppliers

- Criticisms of pay-as-bid pricing
  - Discriminatory (different price for the same product)
  - Lack of transparency

Example

The following bids are submitted for *5-minute* power in a pay-as-bid auction

- Producer 1: 30 MW at 12 $/MWh
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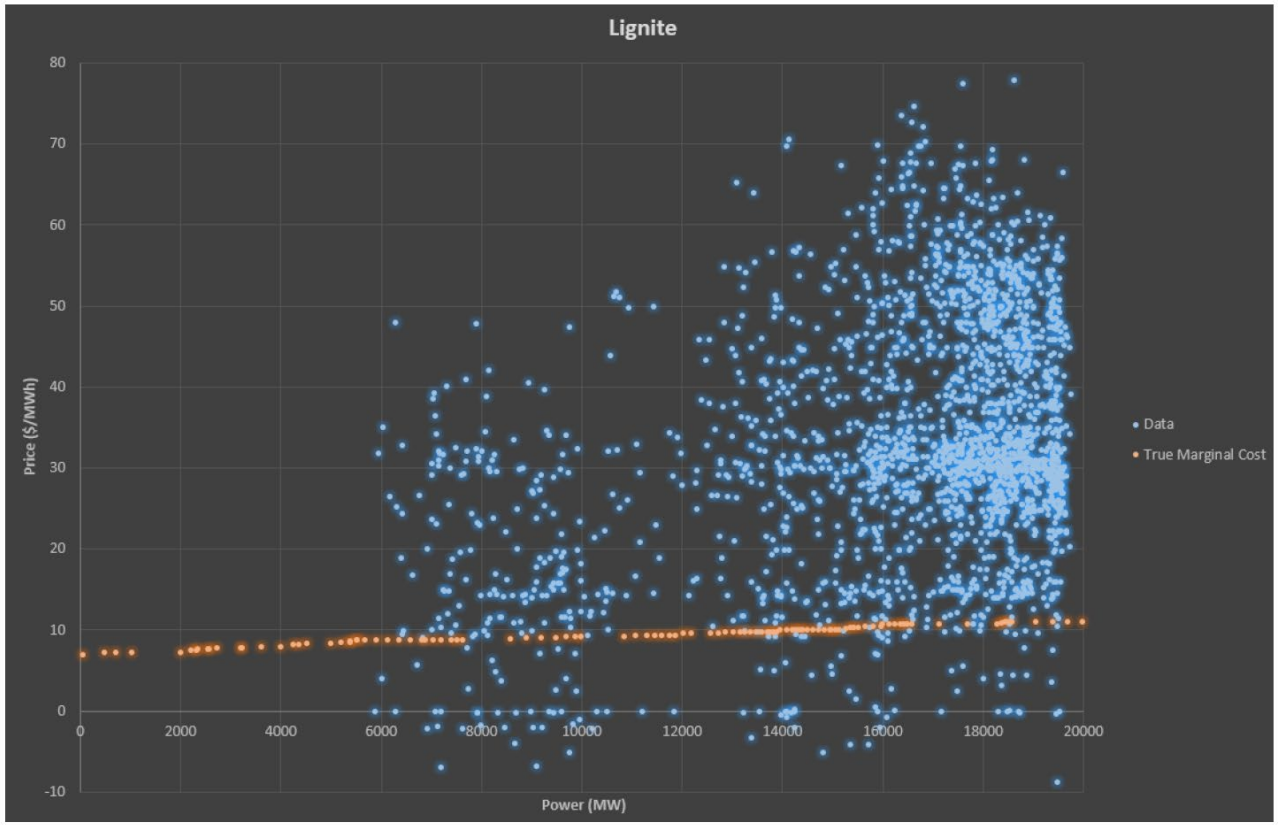
Lignite dispatch in Germany (May-December 2014)



- Which of the blue dots are suffering losses?
- Which of the blue dots could be suspect of keeping power out of the market?

Blueprint of an electricity market

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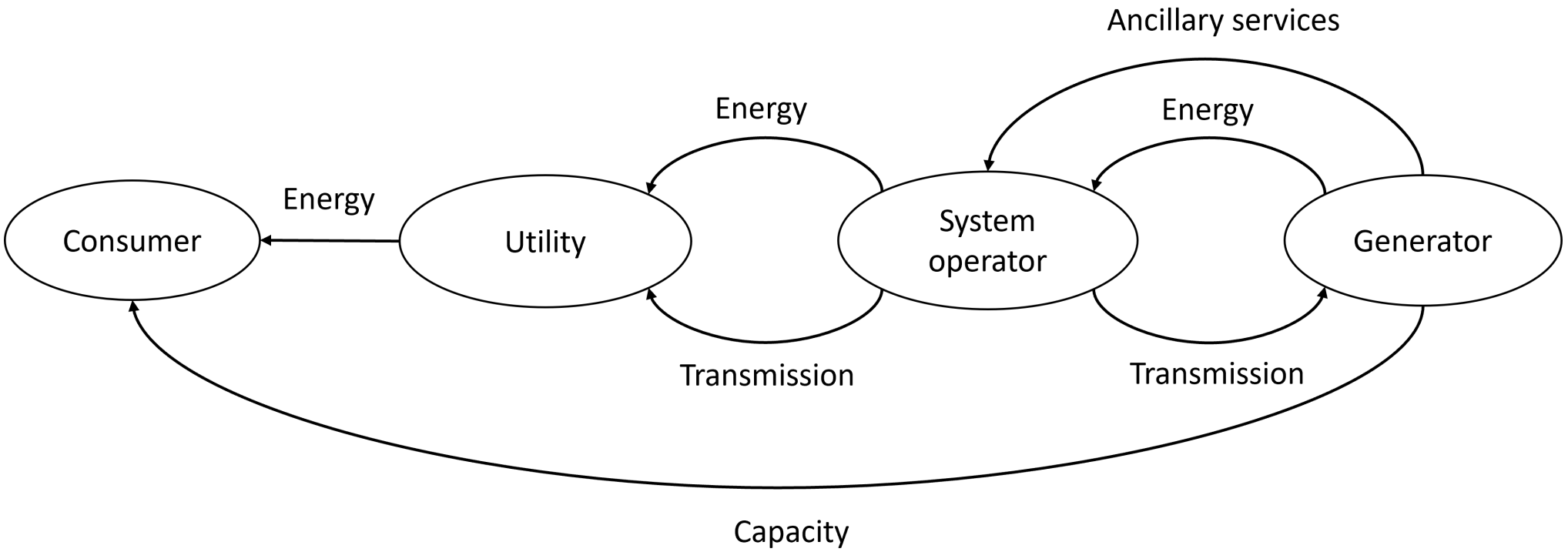

Blueprint variants

What would the following mean?

- An “Energy” arrow from generators to utilities
- An “Ancillary Services” arrow from system operator/generators to utilities
- A “Capacity” arrow from generators to utilities
- An “Ancillary Services” arrow from utilities to the system operator

Example: California and Central Western Europe

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- Pool versus exchange
- Coordination
- Nodal versus zonal pricing

Day-ahead market

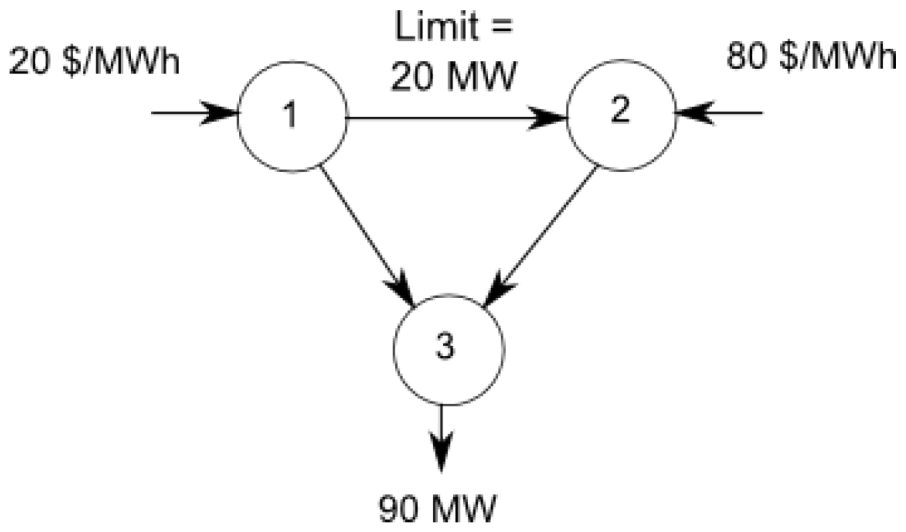
California:

- Pool: detailed bids and uplift payments
- Uniform price for energy (different between nodes)
- Each generator bids individually
- Determines energy, reserve, transmission usage simultaneously

- Central-Western Europe:
  - Exchange: simple bids
  - Uniform price for energy (different between zones)
  - Each firm (not generator) bids individually
  - Determines energy, cross-border transmission usage (not reserve)
  - Ignores Kirchhoff's laws (for the time being)

Ignoring Kirchhoff's laws

All lines have identical characteristics



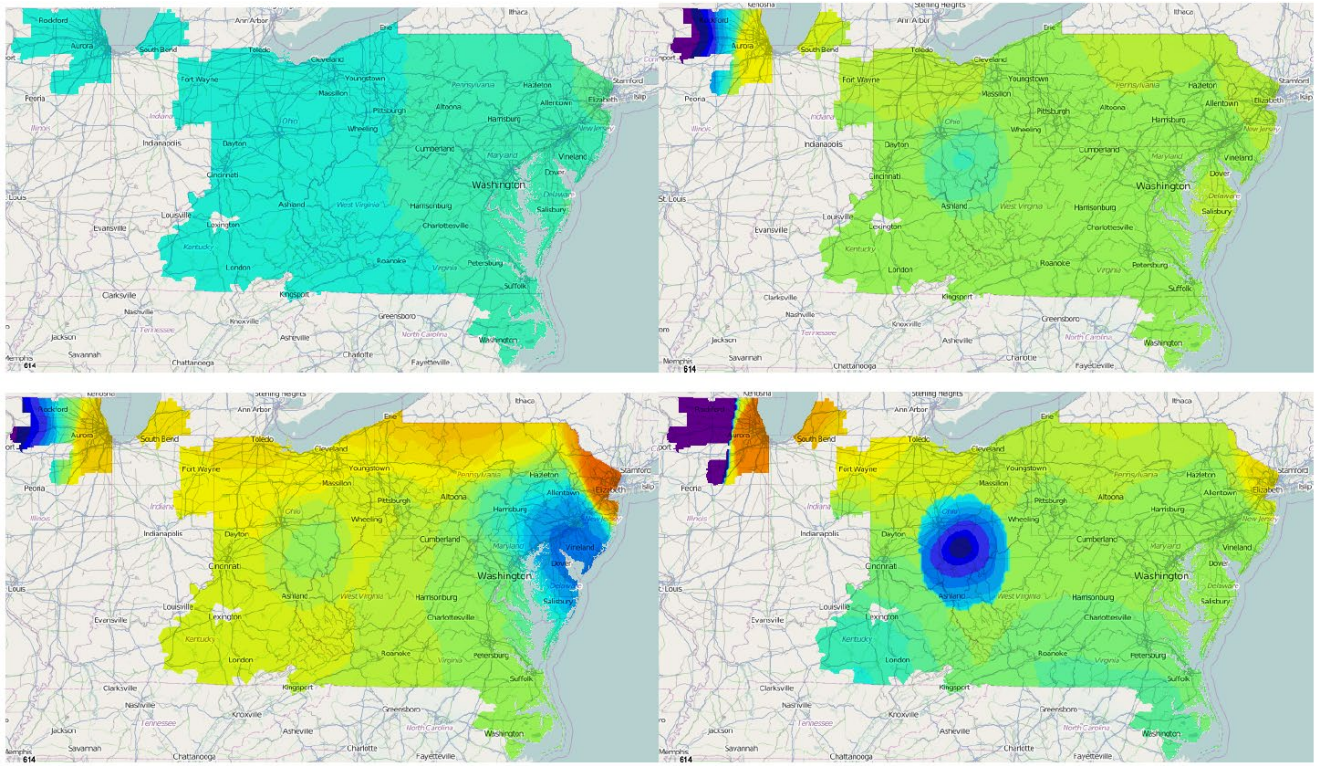
What is the optimal dispatch if we ignore Kirchhoff?

If we account for Kirchhoff?

Nodal pricing versus zonal pricing

- California:
  - **Node**: physical connection point of the network
  - **Nodal pricing**: transmission capacity is bought indirectly by differentiating price of energy at each *node*
- Central and Western Europe:
  - **Zone**: collection of nodes at which electric energy is sold at the same price
  - **Zonal pricing**: motivation is to simplify the trading of energy by reducing the number of markets

Nodal pricing in PJM (February 15, 2014)



05:40 (upper left), 08:40 (upper right), 09:20 (lower left), 09:55 (lower right)

Zonal Pricing

Unique price for each zone (country)

References

[1] A. Papavasiliou, Optimization Models in Electricity Markets, Cambridge University Press

https://www.cambridge.org/highereducation/books/optimization-models-in-electricity-markets/0D2D36891FB5EB6AAC3A4EFC78A8F1D3#overview