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Optimality study of uplift payments with a primal-dual solution approach for Convex Hull Pricing

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Pricing in Electricity Markets

- Wholesale electricity markets:
  - ISO runs the Unit Commitment Problem (UCP) to define the least cost operation.
- Marginal-cost based pricing:
  - Non-convexities of the model are not considered.
  - It is possible that some dispatched units do not recover all the operation costs.
  - A side payment or uplift must be made to ensure incentive compatibility.

$$\text{Total payment} = \text{Energy payment} + \textbf{Uplift}$$

Uplift payments

- Ex-post payment to incentivize units to follow ISO.
- There are two types of uplift:
  - Make-whole payment: based on the losses.
  - Lost opportunity cost: based on the maximum profit.
- Some issues:
  - Distortion of price signal.
  - Possible rise with high RES production.

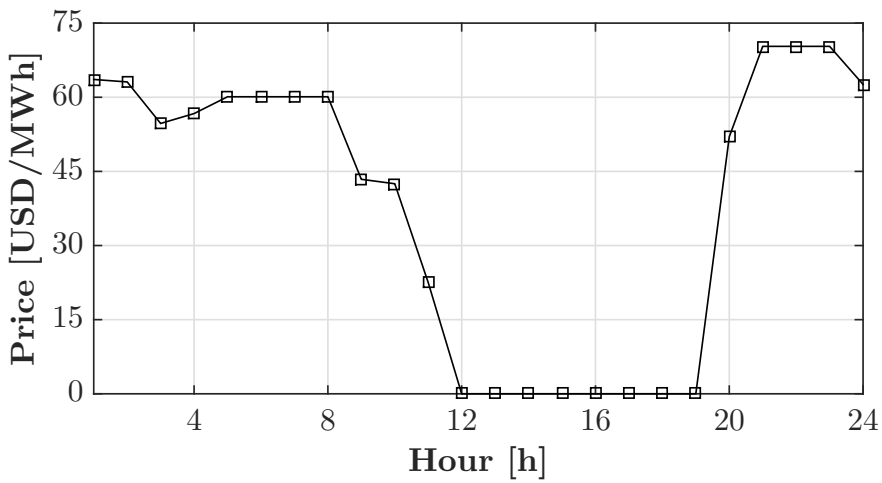


Figure: Marginal cost observed in a bus in northern Chile.

▶ Review of marginal-cost pricing scheme

Convex Hull Pricing

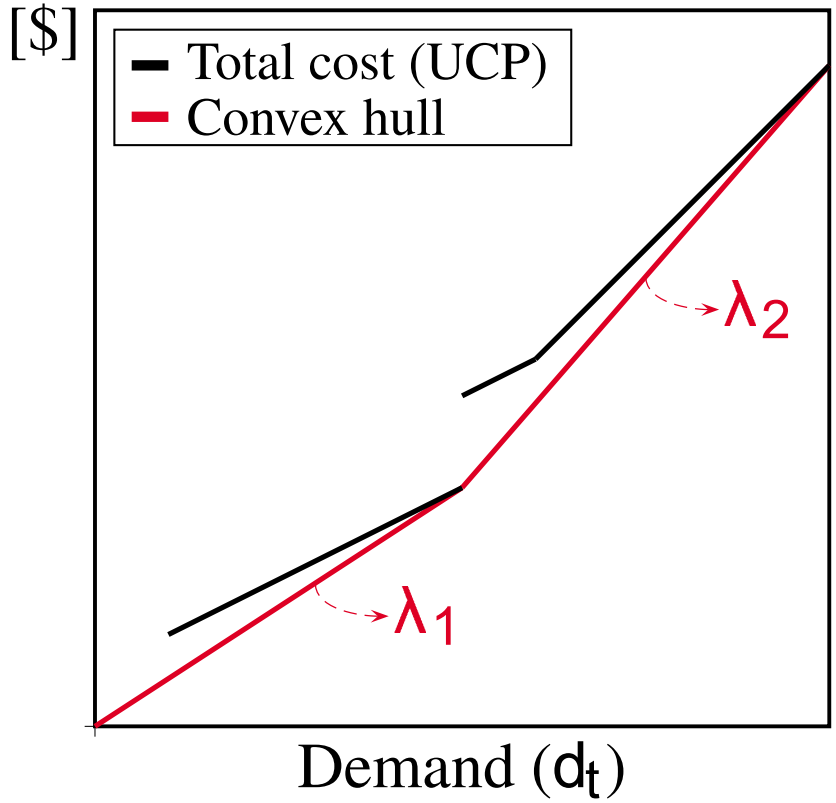
- Pricing method proposed by Gribik et al (2007).
- It minimizes one type of uplifts: lost opportunity cost.
- Price is based on the slope of the convex hull of the UCP cost function.

Unit Commitment Problem :

$$\min \quad \sum_{t \in T} \sum_{g \in G} C_{gt}(u_{gt}, p_{gt})$$

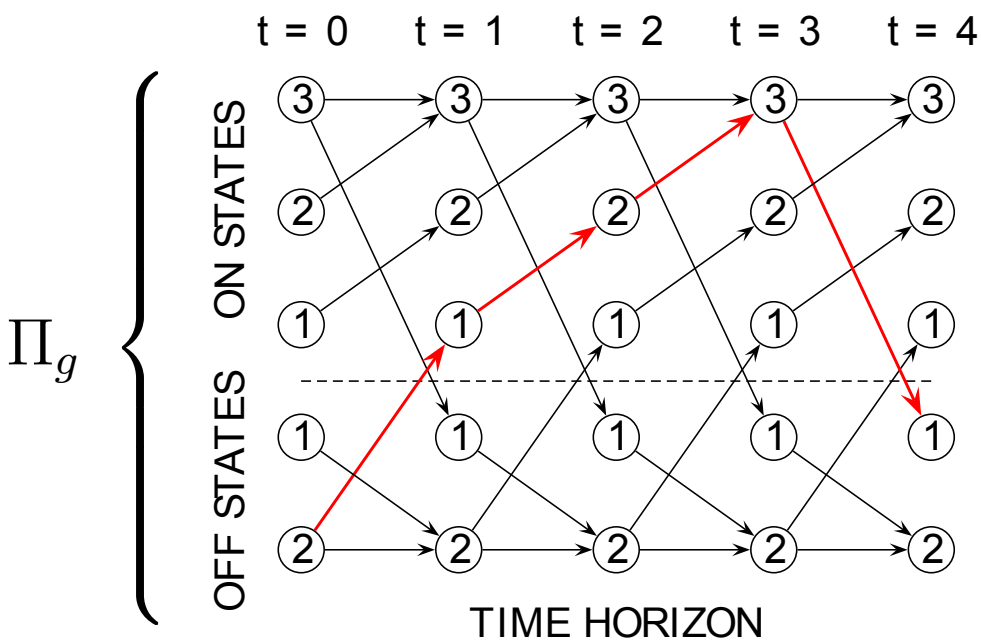
$$\text{s.t.} \quad \sum_{g \in G} p_{gt} = d_t \quad \forall t \in T$$

$$(\mathsf{u}_g, \mathsf{p}_g) \in \Pi_g \quad \forall g \in G$$



Convex Hull Pricing

- Last approaches:
  - Define explicitly the convex hull of the set Π_g.
  - Prices can be obtained solving a continuous problem.
  - However, new features require changes in formulation.
- Our approach:



The model:

- We define variables and parameters from the arcs.
- In fact, UCP now is a set of network-flow problems coupled by system constraints.
- Network-flow constraints are the exact convex hull description of Π_g (without ramping).

Network-flow approach

Pros

- Flexibility: out of ramping constraints, most of the characteristics can be included.
- Formulation is robust: no need to add special constraints.
- Exact convex hull prices and minimum uplift are obtained.

Cons

- Solution time: the formulation is much larger than its compact counterparts.

Proposed solution approach:

+ Based on the primal-dual algorithm of Bienstock et al (2015).
+ The algorithm works with a decomposition scheme, so the large formulation is never solved directly.
+ Prices can be obtained fast for different optimality parameters.

Computational results

- We test the performance of the model and the algorithm with large-scale cases.
- Cases: time-dependent startup costs, minimum up/down time constraints and piecewise-linear generation costs.
- Neither transmission, reserve requirement or ramping constraints are included.

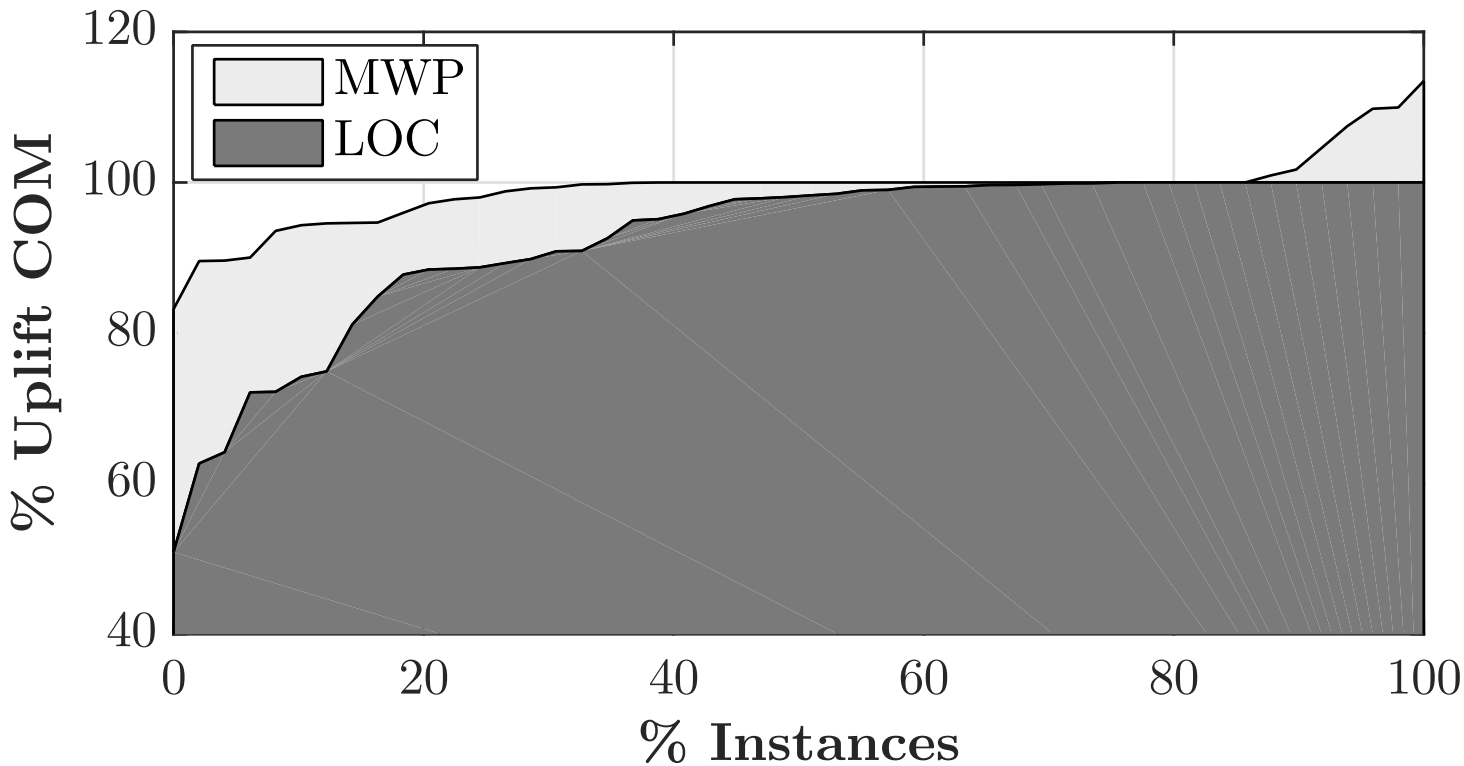
Instances		Time geometric mean [s]		
Units	Periods	BZ 10^{-6}	BZ 10^{-4}	BZ 10^{-2}
50 to 500	24	**5.2**	4.7	4.3
50 to 500	48	**13.5**	12.3	11.0
600 to 1000	24	**20.9**	17.8	15.0
50 to 500	120	**31.1**	26.2	21.4
1100 to 1500	24	**36.2**	30.4	25.6
1600 to 2000	24	**50.3**	44.1	39.5
600 to 1000	48	60.6	51.7	45.9
1100 to 1500	48	92.2	77.1	66.3

Economic results

- Two uplifts studied: Make-whole payment (MWP) and Lost opportunity cost (LOC).
- Prices and uplift payments are calculated for a time horizon of 24 hours.
- The results are divided into two parts:
  - Comparative analysis of the best formulation found in literature with our network-flow model.
  - Sensitivity analysis of the prices with different optimality parameters.

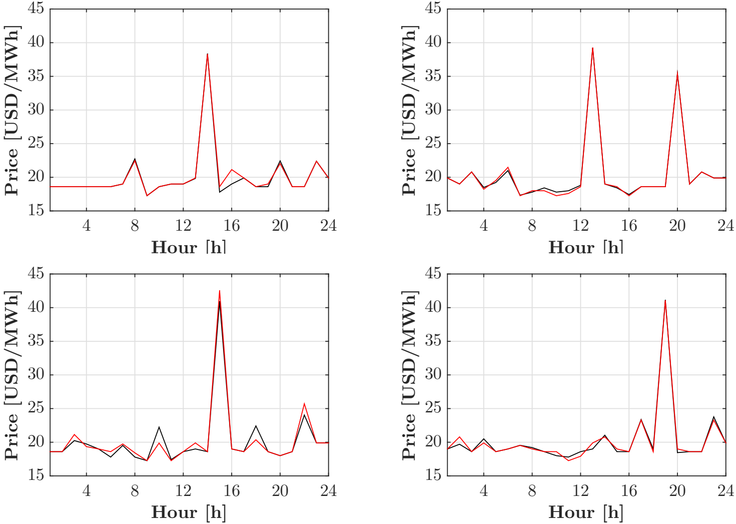
The role of UCP formulation

- The network-flow formulation proves to obtain the minimum uplift in all the cases.
- Less dispersion in make-whole payment (MWP).



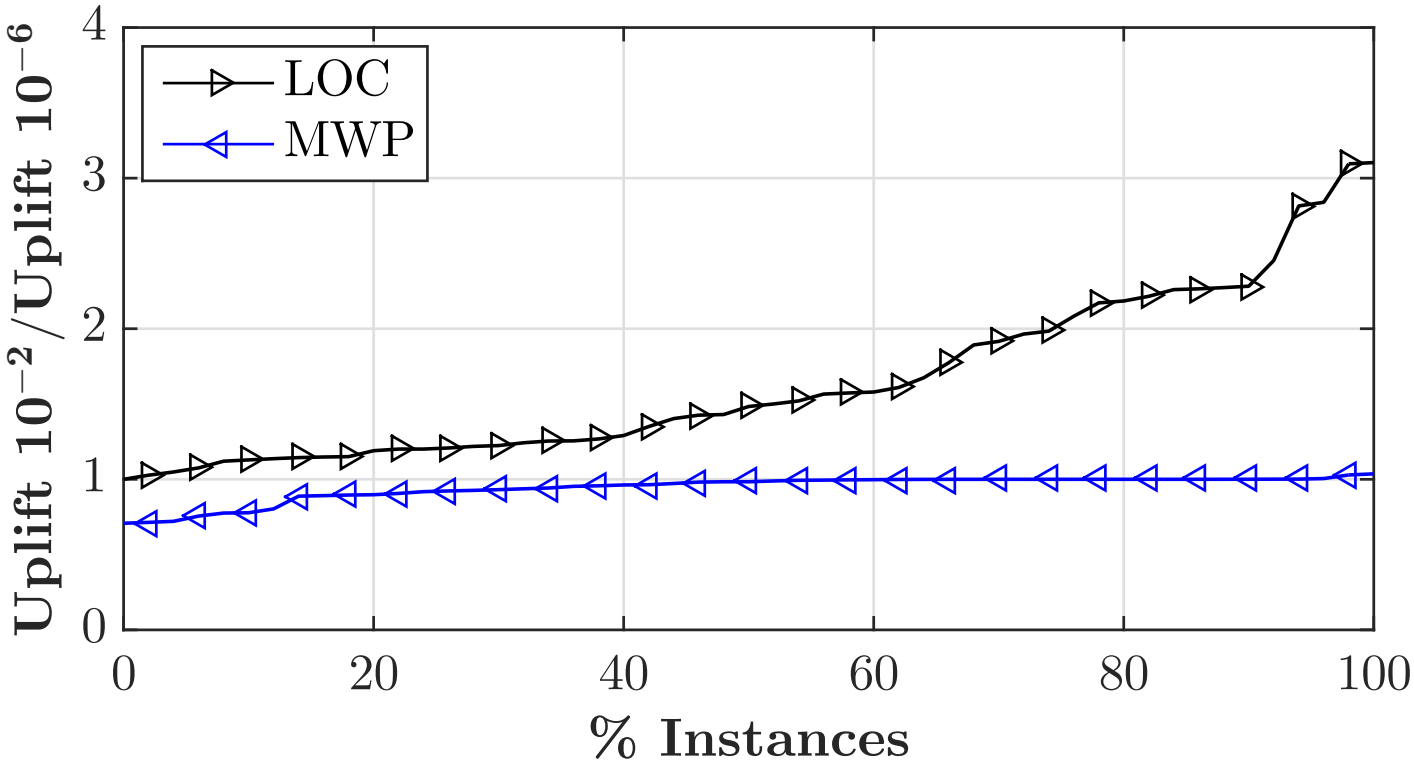
The role of optimality

- Differences in prices are slight, average is close to 1%.



The role of optimality

- The major impact observed in lost opportunity cost (LOC).
- Make-whole payment remains relatively stable to suboptimal prices.



Conclusions

1. We have a flexible and efficient approach to obtain convex hull prices: compactness is not mandatory.
2. Even if no implemented as a side payment, LOC should be considered jointly to MWP.
3. Importance of optimality: slight differences in prices may have important effects over uplifts.

Future Work

- Include ramping and transmission constraints.

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