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The Hidden Properties of Fast Start Pricing

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* The views expressed in this presentation do **not** represent those of ISO New England

The Concern

- Start-up (SU), no-load (NL), and incremental offers are used to make commitment and dispatch decisions
- Traditionally, prices are determined by the optimal dual variables of the convex dispatch problem
  - SU and NL costs (i.e., commitment costs) are not reflected in prices
- Concern: Traditional prices are unable to "**reflect the actual marginal cost of serving load**"*
  - This cost presumably includes Fast Start (FS) commitment costs

* FERC Docket No. RM17-3-000 (December 15, 2016)

The Potential Solutions

- To address the concern, ISOs have proposed and/or implemented a variety of "Fast Start Pricing" methods
  - Each method is meant to, at the very least, incorporate FS commitment costs into prices
- Each FS pricing method has unique properties, some of which are not obvious
- Because the fundamental problem here is nonconvexity, there is no perfect solution

Outline

- Evaluation criteria
- Properties of each FS pricing method
- Fundamental questions on FS pricing
- Conclusion

Pricing Criteria

- Before delving into different FS pricing methods, a set of criteria is needed to evaluate them
- Three principles
  1) **E**fficiency
  2) **T**ransparency
  3) **S**implicity

Pricing Criterion: Efficiency

1) **Efficiency**
   a) Assuming truthful offers, cleared quantities maximize social surplus/minimize total production cost
   b) Given prices and uplift (make-whole + LOC), each unit should want to produce its cleared quantity

Pricing Criterion: Transparency

2) **Transparency**
   a) "Much is known by many" about transaction prices
   b) Everyone knows the prices that others receive/pay

- In the context of FS pricing, LMPs are transparent and uplift is not transparent

Pricing Criterion: Simplicity

3) **Simplicity**

   a) As few prices as possible

      - Uniform price at the same location and time

   b) Price formation process should use simple logic

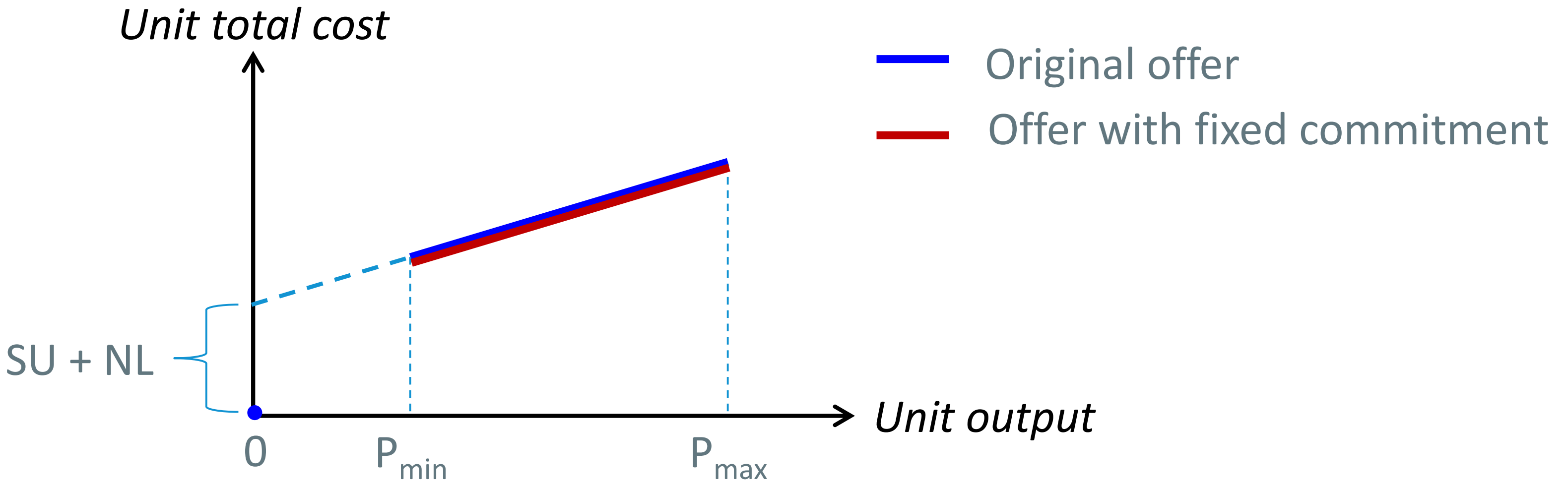
      - Prices are easy to interpret

Categories of Fast Start Pricing

- All FS pricing methods in this presentation derive prices from convex (linear) problems
- Baseline method
  - Fixed commitment pricing
- FS pricing methods
  - Rule-based pricing
  - Convex hull pricing
  - Integer relaxation pricing

Method: Fixed Commitment Pricing

- Unit commitment variables are fixed at optimal values (0 or 1)
  - The resulting linear dispatch problem produces the price
- **Prices are derived from incremental costs and do not reflect Commitment costs (SU and NL)**

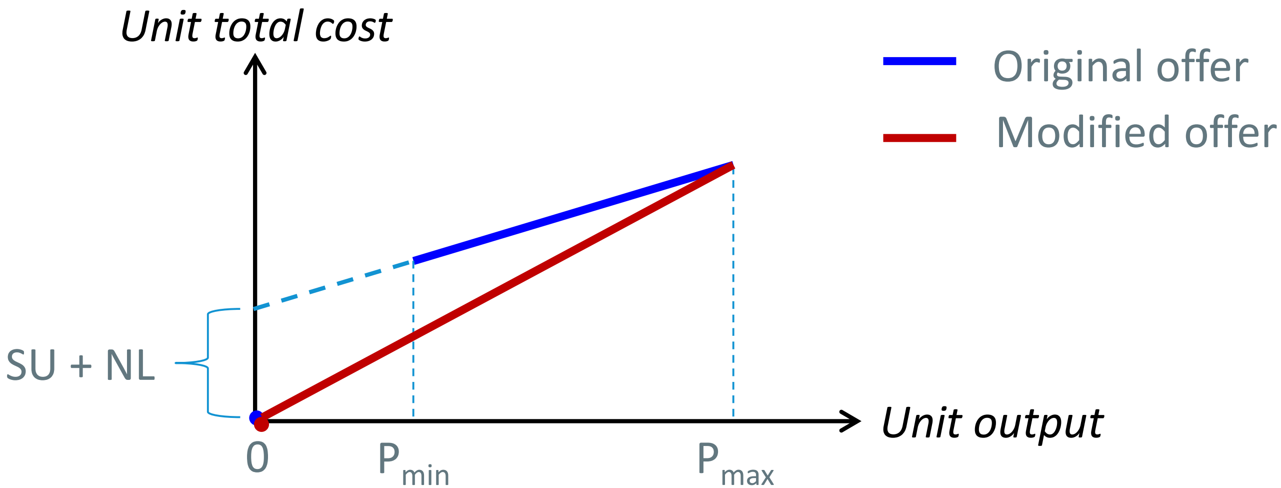


Analysis: Fixed Commitment Pricing

- **Efficient**
  - Efficient resource allocation
  - Prices and make whole payment ensure online units have adequate dispatch-following incentives
- **Not transparent**
  - Make-whole payments can be required by online units
  - Lost opportunity costs can be incurred by offline units
- **Simple**
  - Price obeys the marginal cost pricing concept (i.e., marginal cost of serving the next MW of load)

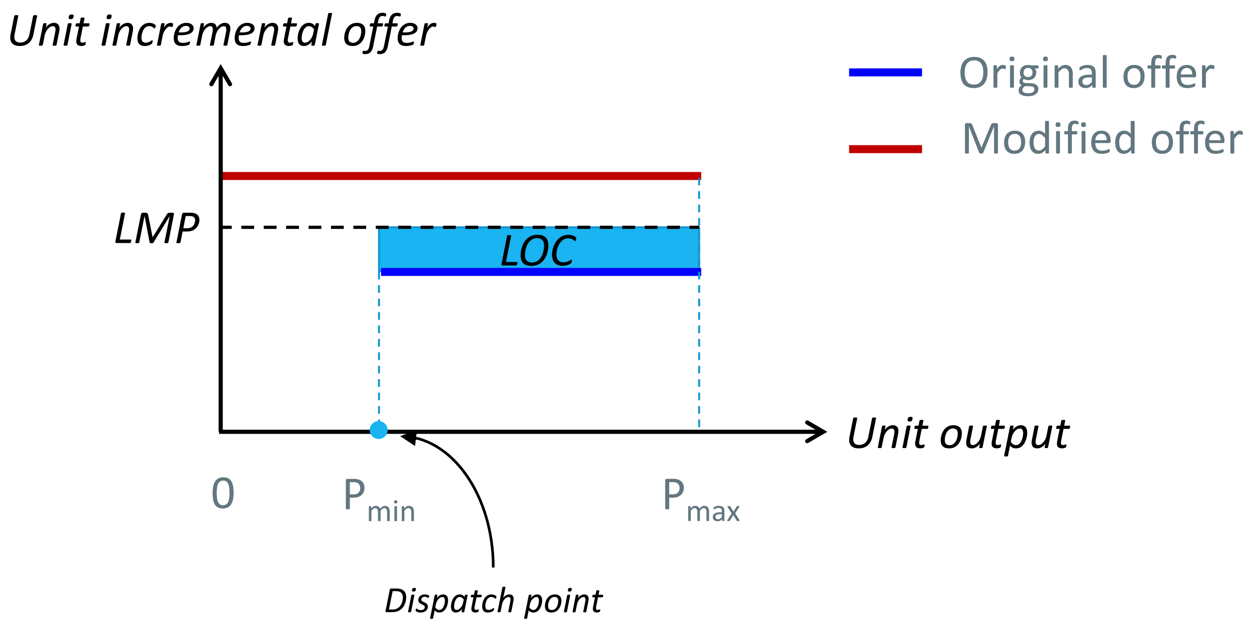
Method: Rule-based Pricing

- Price is derived from the dispatch problem with modified FS offers
- Typically, variations of the following pricing rules are used
  - Relax P_{min} to 0 MW
  - Amortize SU cost over minimum run time and P_{max}
  - Amortize NL cost over P_{max}
- **These rules do not have a rigorous economic justification**



Method: Rule-based Pricing

- **<u>Hidden Property</u>:** *Inconsistent Dispatch & Pricing*
  - The price derived using the modified FS offers may be inconsistent with the cleared quantity
  - Lost opportunity costs/special deviation settlement rules may be needed to ensure dispatch following

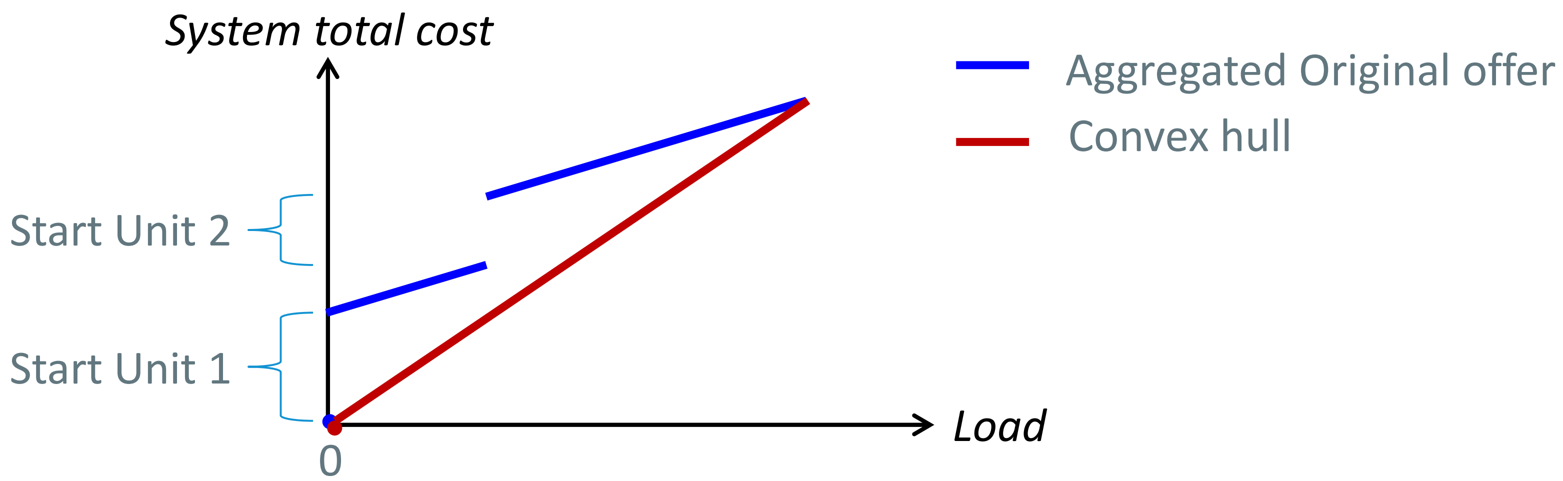


Analysis: Rule-based Pricing

- **Efficient**
  - Combined, prices and uplift ensure that units have adequate dispatch-following incentives
- **Not transparent**
  - Uplift is needed
- **Simple**
  - Price obeys the marginal cost pricing concept (i.e., marginal cost of serving the next MW of load) but is derived from the modified offers

Method: Convex Hull Pricing

- The Lagrangian dual problem for unit commitment is solved
  - Price is the slope of the convex envelope of total cost w.r.t. load
- **Hidden Property**: *Minimization of total uplift*
  - Price minimizes (make-whole + LOC + transmission/reserve revenue shortfall) over commitment problem's time horizon



Analysis: Convex Hull Pricing

- **Efficient**
  - Combined, prices and uplift ensure that units have adequate dispatch-following incentives
- **Not transparent**
  - Convex Hull Pricing minimizes <u>total</u> uplift (make-whole + LOCs + transmission/reserve collection shortages) but may not eliminate it
- **Not simple**
  - Price does not obey the marginal cost pricing concept
    - Price can be the average cost of one or more units (possibly offline)
  - Computationally difficult to solve for the true convex hull price

Method: Integer Relaxation Pricing

- Relax each binary unit commitment variable

$$\{0,1\} \rightarrow [0,1]$$

- While this idea is simple, it has a hidden property

Price is dependent on the problem formulation!

Example: Integer Relaxation Pricing

	P_{min}	P_{max}	Inc. Cost	Commitment Cost	Initial State
U1	0	100	$10	0	On
U2	10	25	$20	$1000	Off

- Load = 105MW
- U2 ramp limit = 20MW
- Single interval commitment problem, assume U1 is always "On"
- The optimal commitment/dispatch solution is
  - U1: Output = 95 MW
  - U2: "On", Output = 10 MW

Example: Two Equivalent UC Formulations

- Formulation 1

$$\begin{aligned} \min \quad & 10p_1 + 20p_2 + 1000x_2 \\ \text{s.t.} \quad & p_1 + p_2 = 105 \\ & p_1 \le 100 \\ & p_2 \le 25x_2 \\ & p_2 \ge 10x_2 \\ & p_2 \le 20 \\ & p_1, p_2 \ge 0 \\ & x_2 \in \{0,1\} \end{aligned}$$

- Formulation 2

$$\begin{aligned} \min \quad & 10p_1 + 20p_2 + 1000x_2 \\ \text{s.t.} \quad & p_1 + p_2 = 105 \\ & p_1 \le 100 \\ & p_2 \le 25x_2 \\ & p_2 \ge 10x_2 \\ & p_2 \le 20x_2 \\ & p_1, p_2 \ge 0 \\ & x_2 \in \{0,1\} \end{aligned}$$

Formulation difference in ramp constraint

- Both formulations have the same feasible region and optimal solution: (p_1, x_2, p_2) = (95MW, 1, 10MW)
- What happens after integer relaxation?

Example: Integer Relaxation of Two Formulations

- Relaxed Formulation 1

$$\begin{aligned} \min \quad & 10p_1 + 20p_2 + 1000x_2 \\ \text{s.t.} \quad & p_1 + p_2 = 105 \\ & p_1 \le 100 \\ & p_2 \le 25x_2 \\ & p_2 \ge 10x_2 \\ & p_2 \le 20 \\ & p_1, p_2 \ge 0 \\ & 0 \le x_2 \le 1 \end{aligned}$$

Equivalently,

$$\begin{aligned} \min \quad & 1050 + 10p_2 + 1000x_2 \\ \text{s.t.} \quad & p_2 \ge 5 \\ & p_2 \le 25x_2 \\ & p_2 \ge 10x_2 \\ & p_2 \le 20 \\ & p_2 \le 105 \\ & p_2 \ge 0 \\ & 0 \le x_2 \le 1 \end{aligned}$$

- Relaxed Formulation 2

$$\begin{aligned} \min \quad & 10p_1 + 20p_2 + 1000x_2 \\ \text{s.t.} \quad & p_1 + p_2 = 105 \\ & p_1 \le 100 \\ & p_2 \le 25x_2 \\ & p_2 \ge 10x_2 \\ & p_2 \le 20x_2 \\ & p_1, p_2 \ge 0 \\ & 0 \le x_2 \le 1 \end{aligned}$$

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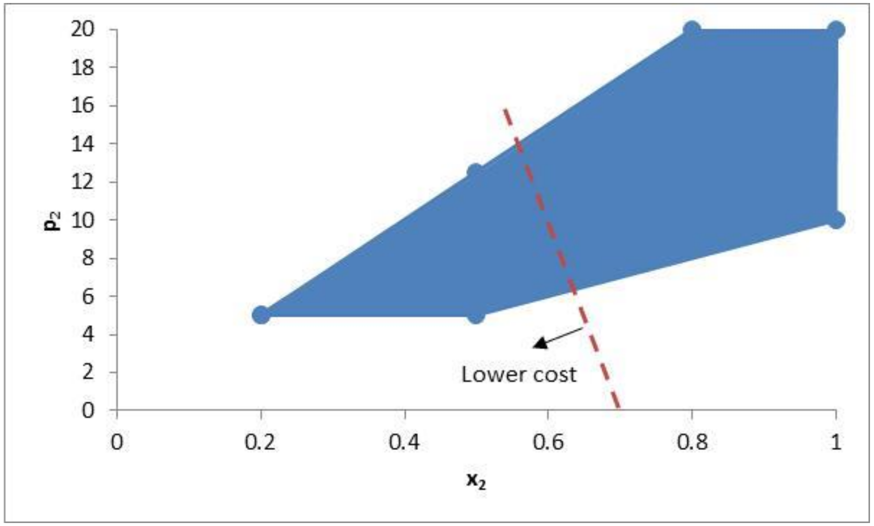
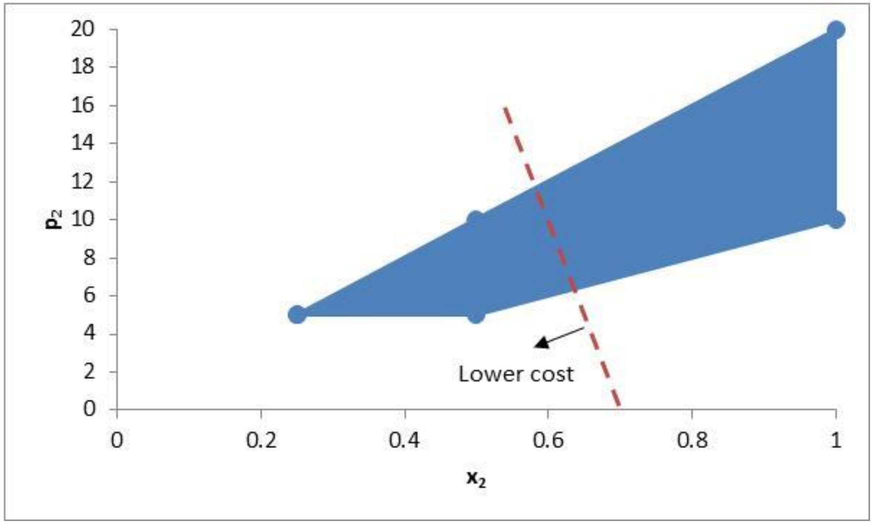
Relaxed commitment ($0 \le x_2 \le 1$ in both formulations)

Example: Feasible Regions of Relaxed Formulations

- Relaxed Formulation 1



- Relaxed Formulation 2



- Optimal solution
  - **U2: Commitment = 0.2,**
    Output = 5 MW
  - U1: Output = 100 MW

- Optimal solution
  - **U2: Commitment = 0.25,**
    Output = 5 MW
  - U1: Output = 100 MW

Example: Integer Relaxation Prices

- What is the LMP for Formulation 1?
  - The next MW of load would be satisfied by U2
  - The binding constraint
    $$p_2 \le 25x_2$$
    implies a fractional U2 commitment increase (**1/25**) associated with a 1 MW output increase

LMP = 20 + 1000/**25** = **60**

U2 incremental cost

U_2 "amortized" commitment cost

- What is the LMP for Formulation 2?
  - The next MW of load would be satisfied by U2
  - The binding constraint
    $$p_2 \le 20x_2$$
    implies a fractional U2 commitment increase (**1/20**) associated with a 1 MW output increase

LMP = 20 + 1000/**20** = **70**

U_2 incremental cost

U_2 "amortized" commitment cost

Example Conclusion: Integer Relaxation Pricing

- Integer relaxation pricing **depends on the UC formulation**
  - Reformulating the UC problem is not unusual; ISOs use reformulations to improve computational performance
  - With integer relaxation pricing, the ISO has to consider the potential effects of UC reformulations on prices
- Without the complete mathematical formulation, integer relaxation is **not a well-defined pricing scheme**
  - **The problem formulation should not impact the market outcome**
- Uplift is still necessary

Analysis: Integer Relaxation Pricing

- **Efficient**
  - Combined, prices and uplift ensure that units have adequate dispatch-following incentives
- **Not transparent**
  - Uplift is needed
- **Not simple**
  - Price depends on the UC formulation and is hard to explain
  - For real-time single-interval pricing, the ISO <u>cannot</u> directly relax the multi-interval commitment problem
    - Instead, a single-interval "commitment-type" problem that amortizes commitment costs (similar to Rule-based Pricing) must be formulated and relaxed

Summary of FS Pricing Methods

	Efficiency	Transparency	Simplicity
Fixing Commitment	Yes	No	Yes
Rule-based	Yes	No	Yes
Convex Hull	Yes	No*	No
Integer Relaxation	Yes	No	No

*If the size of total uplift is the only measure of transparency, Convex Hull Pricing is the "most transparent" approach

There is no perfect price for a nonconvex problem!

Fundamental Questions on FS Pricing

- What costs should be reflected in price? Is the answer dependent on length of the market interval (e.g., DAM or RTM)?
- How does FS pricing relate to the missing money issue?
- How should Transparency and Simplicity be balanced?
- Does FS pricing inadvertently mimic one-part bidding?

No clear answers from economic theory!

Conclusion

- FS pricing is an imperfect solution for a **nonconvex pricing** problem
- The **Efficiency-Transparency-Simplicity** criteria can be used to compare different FS pricing methods
- **All** existing FS pricing methods have drawbacks
- **Hidden properties** of FS pricing were discussed
- **Broader questions** on FS pricing remain unanswered

Questions