Market Pricing and Uplift

New Approaches to Known Issues

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Overview

- Methodologies used in U.S. ISOs to perform unit commitment and dispatch and to calculate market prices lead to the need to pay uplift.
  - Uplift is the gap between the revenues collected in market settlements, and the compensation that generators (and possibly loads) require, based on their bids, to be willing to provide no more and no less than the scheduled quantities at market prices.
  - The magnitude of the uplift depends on the methodology used to calculate market prices.
  - There is generally no set of market prices that would induce profit-maximizing generators and loads to voluntarily follow least-cost commitment and dispatch without uplifts.
  - Present research explores and compares methods for calculating market prices and resulting uplifts.

Unit Commitment and Markets

- ISOs in the U.S. have moved steadily towards a consensus market design consisting of:
  - Bid-based, financially binding day-ahead market schedules based on security constrained day-ahead unit commitment and economic dispatch (SCUC and SCED);
  - Reliability commitment and bid-based security constrained real-time dispatch;
  - Locational prices for day-ahead and real-time settlements;
  - Co-optimization of markets for energy and ancillary services;
  - Financial transmission rights.
- We focus on a Day-Ahead energy market in this presentation for simplicity.

Day-Ahead Unit Commitment and Dispatch

- Least-cost unit commitment is facilitated by allowing bids that correspond to the physical reality of generation plant operation and include, in addition to incremental energy costs, such terms as:
  - Start-up costs and times;
  - Minimum generation blocks and costs (e.g. no-load costs);
  - Minimum run times and down times;
  - Ramp rates.
- Based on these bids, unit commitment and economic dispatch algorithms are used to optimize schedules.

Marginal Cost Pricing

- The marginal cost of serving load at a node for a given unit commitment is well defined and easy to compute.
  - Since the commitment is given, we will term this the restricted marginal cost or MC-R at the node.
- Start-up and no-load costs are not included in MC-Rs.
  - In response to an infinitesimal change in demand, the market will not change the committed resources.
  - Only the energy output of committed resources will change so only incremental energy costs affect MC-Rs.

Impact of Definition of MC-R

- MC-Rs may not be monotonically increasing with demand.
  - As new resources are committed to meet increasing demand, MC-Rs can go up or down.
- MC-Rs may not be market-clearing prices.
  - At market clearing prices, profit maximizing generators would be willing to commit and dispatch themselves at a level equal to that at which benefit maximizing demands would want to consume.
    - No remaining arbitrage opportunities at market clearing prices.
  - Discrete nature of commitment decisions, start-up costs, and no-load costs may prevent the existence of a market-clearing price.

Unit Commitment and Origin of Uplift

- Uplift arises from the complexity and lumpiness (technically, non-convexity) of the unit commitment problem.
  - The problem is that there are discrete decisions, related costs, and inter-temporal constraints associated with unit commitment, not just incremental energy costs.
- Uplifts provide incentive for participants to follow least cost schedules.
  - Uplifts can cover costs not covered by price for dispatched units.
  - Uplifts can cover opportunity costs for units not dispatched at their maximum profit levels.

Example (Two Units)

- Two units offer into market.
  - Each has two blocks with 100 MW in each block.

Offer Data				
	Min MW for block	Max MW for block	G1	G2
Fixed Cost ($)			0	6000
Block 1 Inc Cost ($/MWh)	0	100	65	40
Block 2 Inc Cost ($/MWh)	100	200	110	90

Example

- Assume demand is 190 MW.
- Least-cost commitment and dispatch is:
  - G1 committed and dispatched at 90 MW.
  - G2 committed and dispatched at 100 MW.
- G1 is the marginal unit and it sets MC-R at $65/MWh.
- MC-R does not cover the operating costs of unit G2. Total uplift is $3,500.
- There is no price at which G1 and G2 would maximize their profits by producing exactly 190 MW.
  - At any price above $65/MWh and below $95/MWh, G1 would want to produce 100 MW and G2 would want to produce 0 MW.
  - At any price above $95/MWh and below $110/MWh, G1 would want to produce 100 MW and G2 would want to produce 200 MW.
  - At exactly $95/MWh, G1 would want to produce 100 MW and G2 would be willing to produce either 0 MW or 200 MW but not any amount between.
- There is not a market clearing price when demand is 190 MW.

Alternative Approaches to Pricing and Uplift

- *Restricted Model (O'Neill, Sotkiewicz, Hobbs, Rothkopf, Stewart)*
  - Treats the unit commitment as known and includes as constraints in the SCED. Calculates MC-R for energy and prices the constraints used to model the fixed commitment. Computationally simple.
- *Dispatchable Model (similar to approach used in NYSIO)*
  - For the price calculation, treats all units as dispatchable down to 0 MW, with variable costs equal to incremental energy costs plus average fixed costs (at full load); also computationally simple.
- *Convex Hull Model (Gribik, Hogan, Pope)*
  - Calculates market prices from a convex approximation of the total cost curve that is as close as possible to the total cost curve, but no greater at any level of load; could be more complex to implement.

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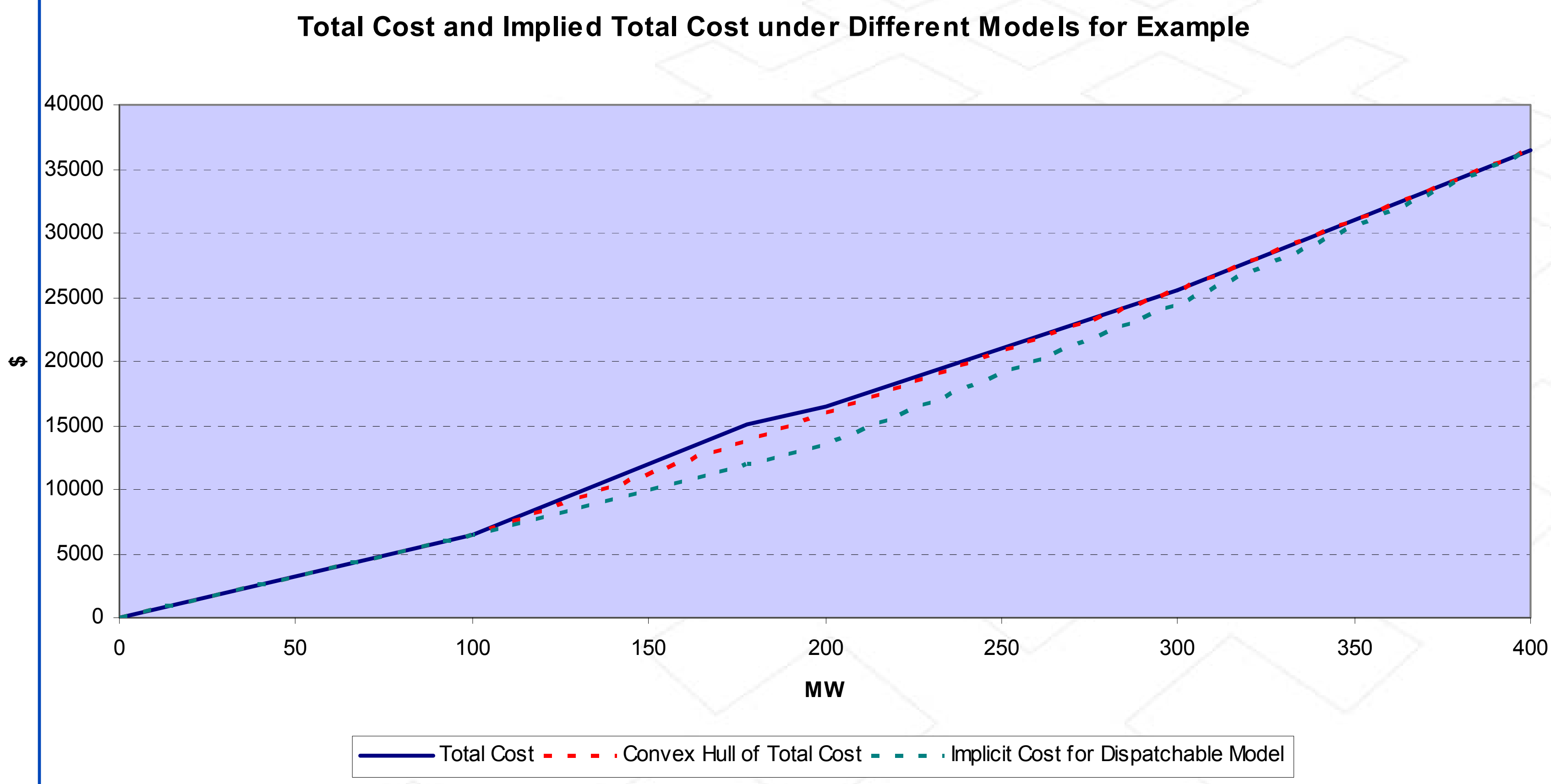
Alternative Approaches to Pricing and Uplift

- The market prices and uplift resulting from the three approaches differ in magnitude and volatility.
  - *Restricted Model*
    - Energy price given by MC-R. Prices on commitment constraints could be viewed as components of uplift.
  - *Dispatchable Model*
    - Produces an energy supply curve with marginal costs that increase as load increases.
    - Can lead to larger than necessary uplift.
  - *Convex Hull Model*
    - Produces an energy supply curve with marginal costs that increase as load increases.
    - Leads to the minimum uplift.


Total Cost and Implied Total Cost under Different Models for Example
40000
35000
30000
25000
20000
15000
10000
5000
0
$
0
50
100
150
200
250
300
350
400
MW
Total Cost
Convex Hull of Total Cost
Implicit Cost for Dispatchable Model

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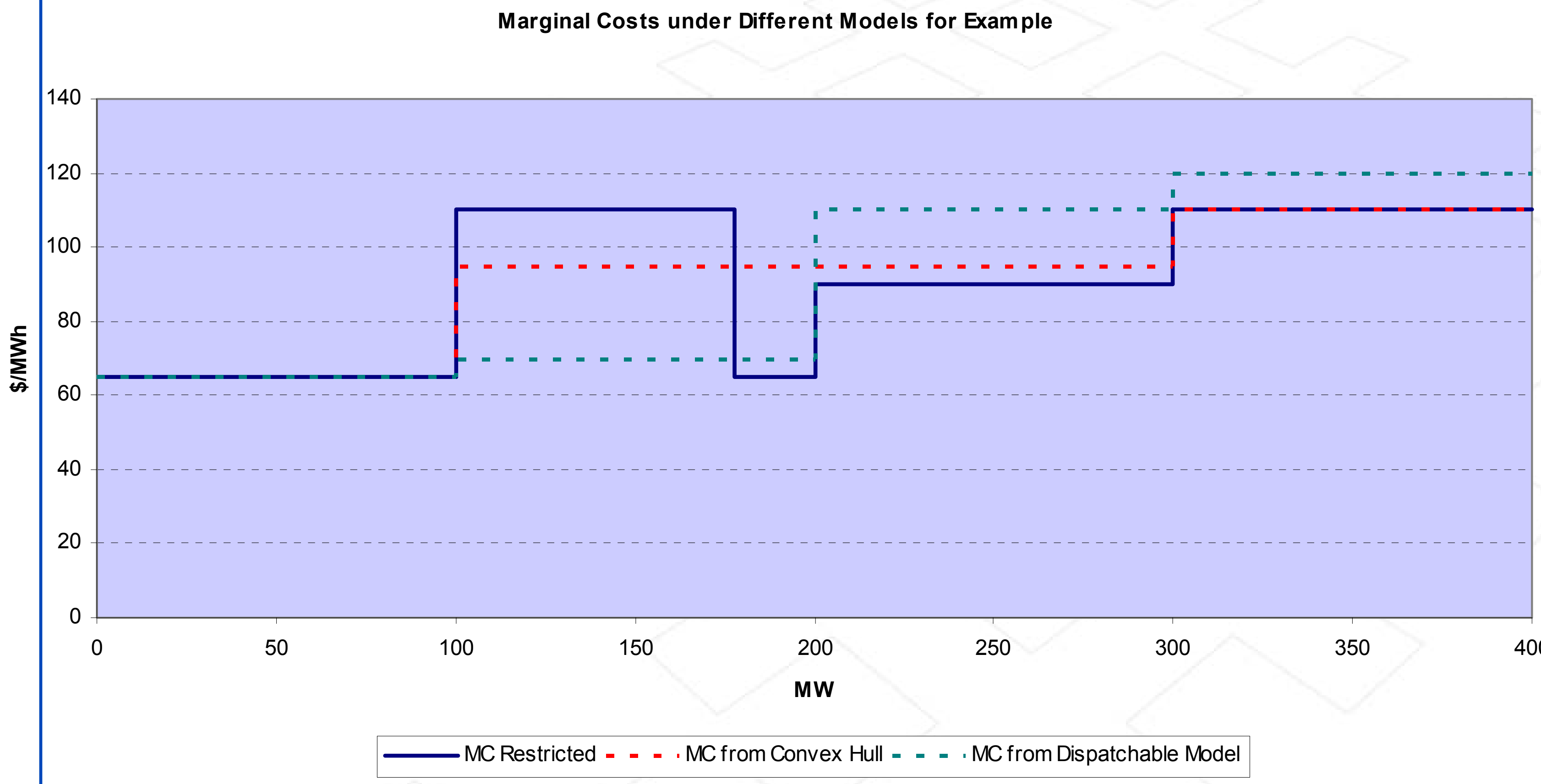

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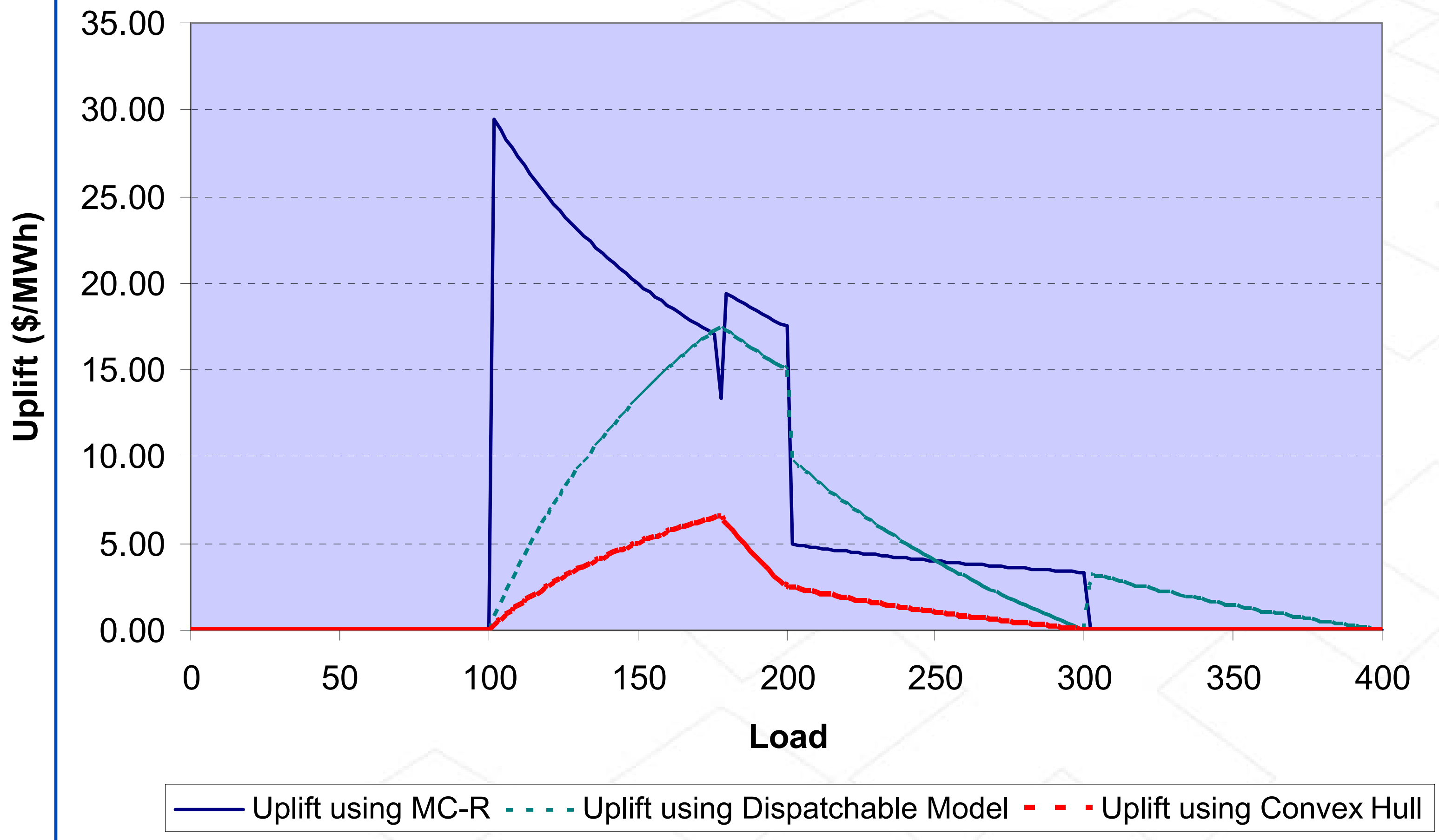
Uplift under Different Models for Example



Forming the Convex Hull of the Total Cost Function

- The convex hull of the total cost as a function of the quantities to be priced can be calculated by forming a partial dual of the unit commitment problem.
  - The constraints that enforce the limits on the quantities to be priced are multiplied by Lagrange multipliers and moved into the objective function.
  - The resulting function is maximized over the Lagrange multipliers.
- This is the Lagrangian Relaxation (LR) of the unit commitment problem.
  - The LR techniques that were state-of-the-art unit commitment algorithms in the 80s and 90s can form the basis of pricing algorithms.

Convex Hull Prices Minimize Uplifts

- It is not a coincidence that uplift is minimized under the Convex Hull Model.
  - Prices that solve the Convex Hull Model are also prices that solve the dual of the unit commitment problem.
  - The difference between the value of the dual of the unit commitment problem and the value of the unit commitment problem is known as the duality gap.
    - The duality gap is equal to the total uplift needed to support a given least-cost unit commitment schedule.
  - Since the prices produced by the Convex Hull model minimize the duality gap, they also minimize uplift.

Next Steps

- Further work is being conducted. Areas to be addressed include:
  - Investigate further the behavior of alternate pricing approaches.
  - Investigate methods of simplifying the Convex Hull problem, e.g. selecting a limited set of transmission constraints to include.
  - Investigate performance of methods for solving the Convex Hull problem.

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