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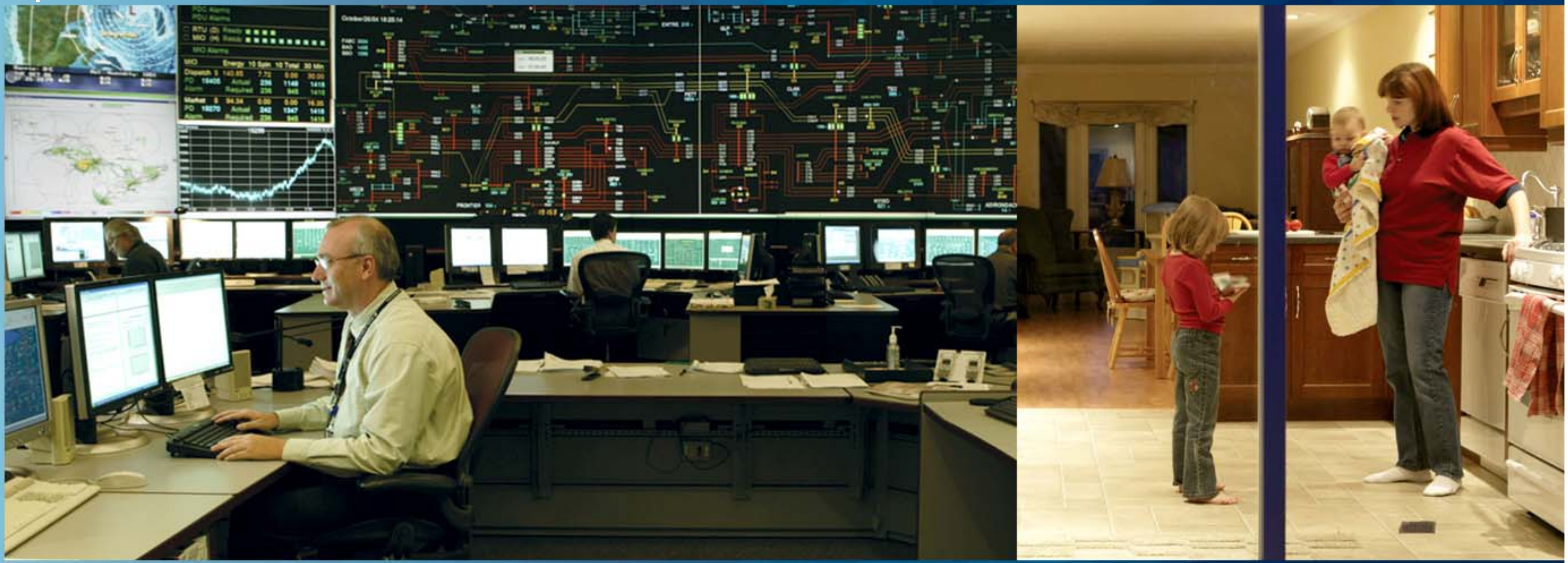
Fundamentals of Pricing Under Temporal Optimization

MPWG

April 19, 2005



Presentation Outline

- **Theoretical Perspective**
- Current MIO Formulation and Prices
- Simulation Results Illustration

Economic Objectives

Dispatch

- Coordinate the simultaneous production and consumption of electricity in accordance with the offers and bids, and electricity industry reliability rules/standards so as to achieve a "least cost bid dispatch"

Temporal Optimization

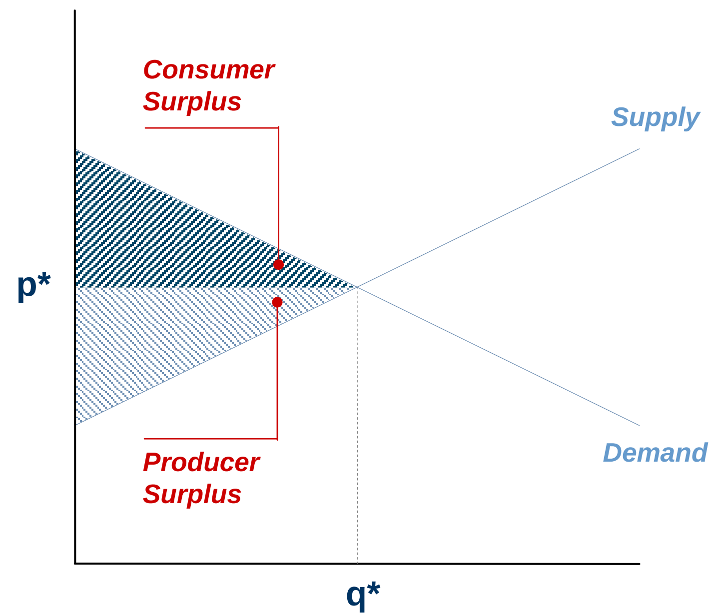
- Achieve least cost dispatch as determined over a specific time period (e.g. hour, day, week)

The Market Clearing Price

- What is it:
  - marginal or incremental price of the next (≅ last) unit (offer or bid) of electricity scheduled (or dispatched)
  - mathematically it is the shadow price determined from the dispatch algorithm
- Only the prices of flexible resources, i.e. those which can be dispatched up or down can set the marginal cost
- Question: Is this the "correct" price in all instances?

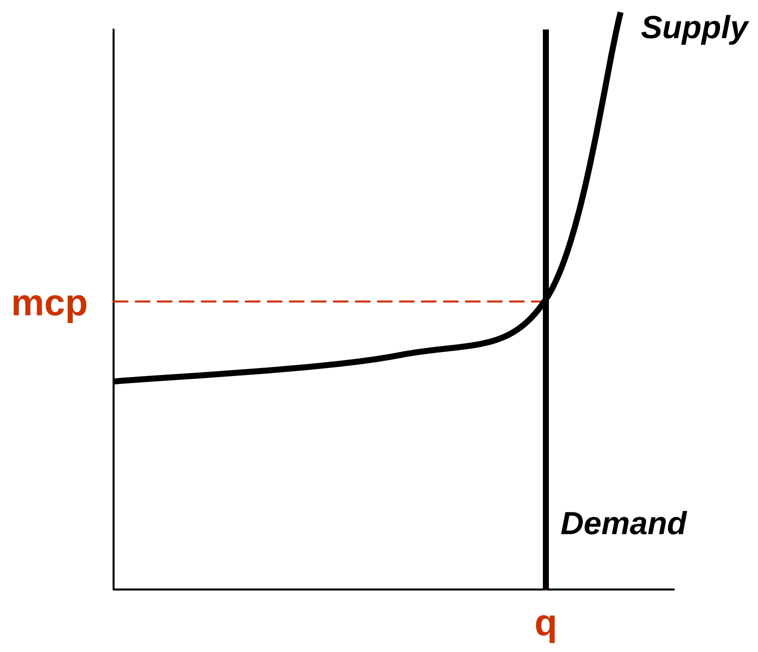
The Economic Optimum

- (p*, q*) is the equilibrium point at which:
  - the marginal cost of production is equal to the marginal benefit from consumption
  - the sum of the consumer and producer surpluses are maximized
  - there are no further possible gains from trade, i.e. moving to a point other than q*, would lead to trades which would improve participant positions



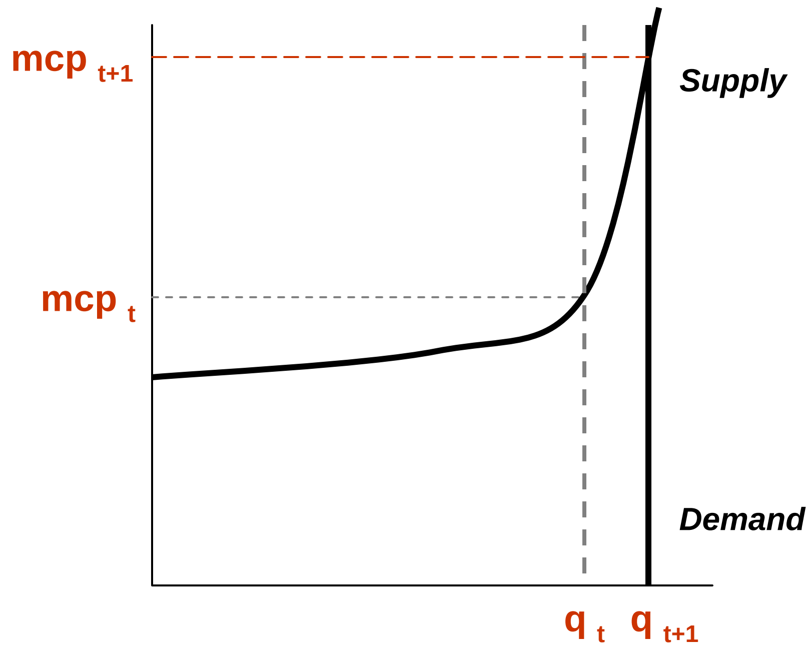
The Economic Reality

- The supply curve is non-linear
- Currently the demand curve is extremely steep (~vertical)
- Under "myopic" optimization resources are dispatched based entirely on current conditions; blind to the future



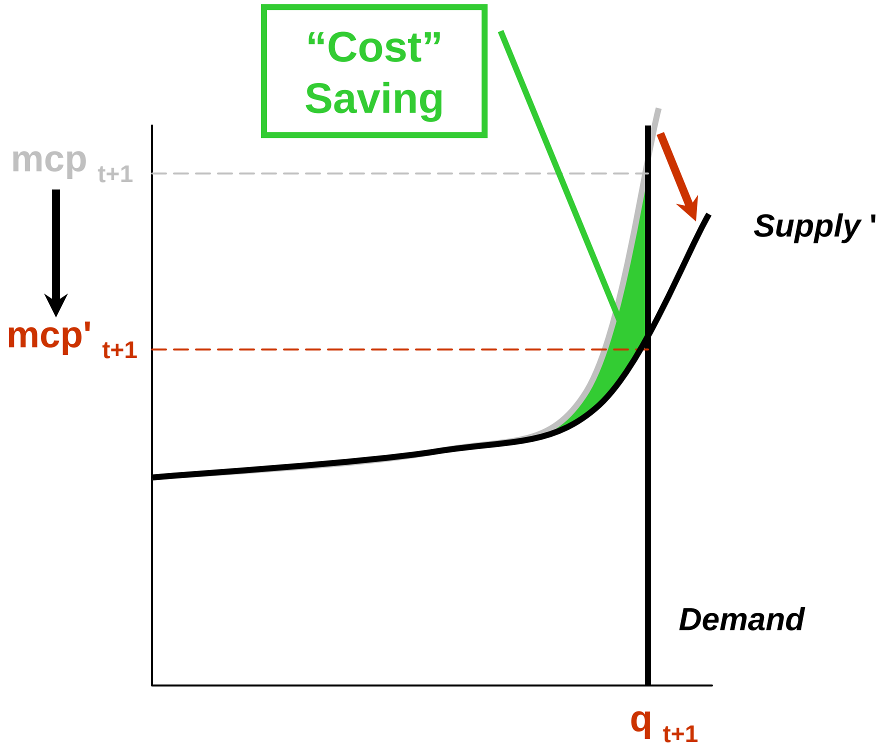
Consequence of Myopic Optimization

- The resource capability available in each interval is largely a consequence of what happened to be dispatched in the immediately preceding interval.
- A more economic or optimum dispatch may have been possible with knowledge and consideration of future needs (ramp units early)



Consequence of Dispatching Resources In Advance

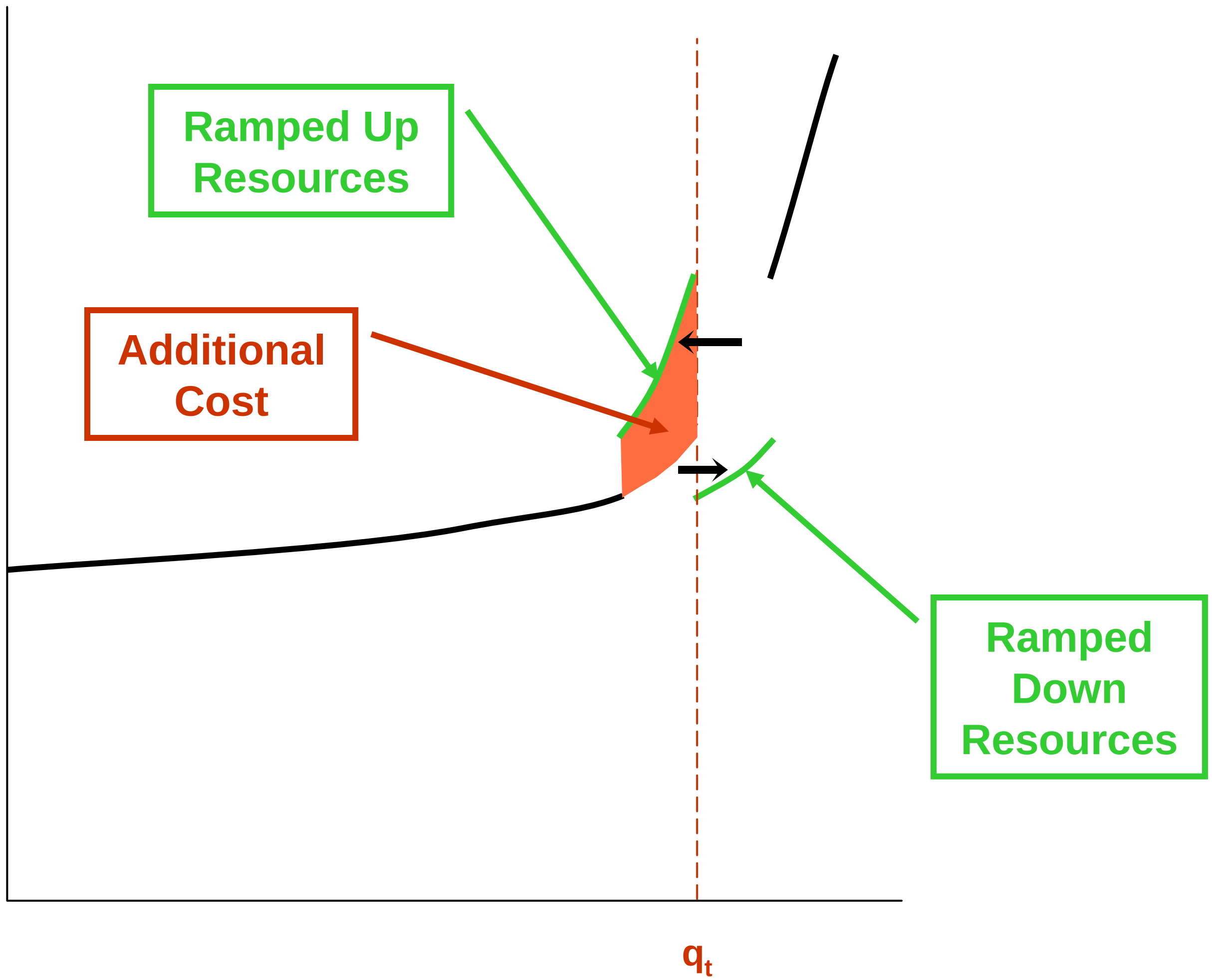
- Early dispatch of higher priced ramp limited resources can improve the offer curve for the future interval.
- If optimum then cost savings more than additional cost of advanced dispatch
- Incremental price in future interval is lower



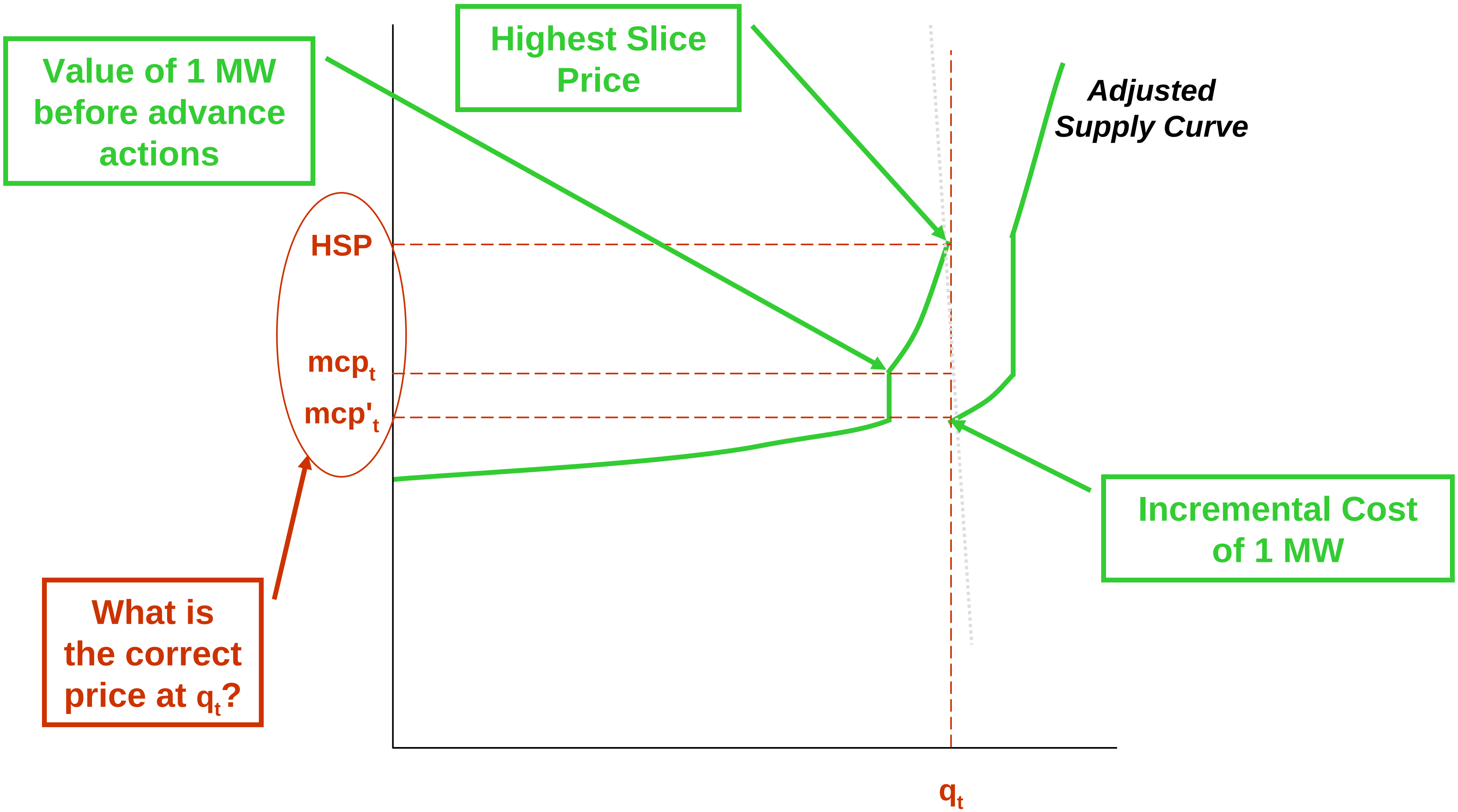
Advance Actions

- Adjust dispatch of resources to meet future conditions (higher demand, higher ramp, altered supply).
  - higher priced resources (typically non quick-start) are dispatched up
  - lower priced resources are dispatched down to maintain demand/generation balance.
  - incremental (i.e. shadow) price is lowered
  - additional cost is incurred

Impact in the Advance Interval



Pricing in Advance Interval



The Economic Questions

- Who should bear costs of advance actions?
- What is the definition of the correct price?
- What is correct clearing price for the interval at which advance action was taken?
- Under what conditions we will deviate from (i.e. compromise) the incremental or marginal price?
- What is the desired response?

Recall Our Pricing Principles

1. Efficiency
   – yield efficient outcomes
2. Fairness
   – cost causality & no inappropriate wealth transfers
3. Reliability
   – incentive to follow instructions and ensure adequacy
4. Transparency
   – simple, understandable & reflect market actions
5. Robustness
   – functioning of market not readily upset

The Answer is not Obvious

Need to pre-load resources may be caused by:

- increase in demand;
- market design, e.g. "strategic" offer to achieve desired dispatched; or
- industry practices, e.g. top of hour change in import/export schedules.

- Who should bear the cost and how?

Presentation Outline

- Theoretical Perspective
- **Current MIO Formulation and Prices**
- Simulation Results Illustration

The Current MIO Formulation

- Each MIO run performs 2 passes.
- Pass 1 performs an inter-temporal optimization across "critical" intervals (up to 5 intervals) in the MIO study period (55 Minutes or 11 intervals).
  - Non-linear constraints that relate the dispatches of two intervals are either linearized (when ramp limited) or ignored (during periods of steady operation).
  - Provides Pass 2 minimum and maximum limits for resources to achieve a "near" optimum solution.

The Current MIO Formulation (cont.)

- Pass 2 performs a "myopic" optimization (with accurate constraints for each critical interval in the MIO study period.
- The output of a resource is constrained in order to satisfy the dispatch calculated in pass 1 for the subsequent (critical) interval (except for the last interval).

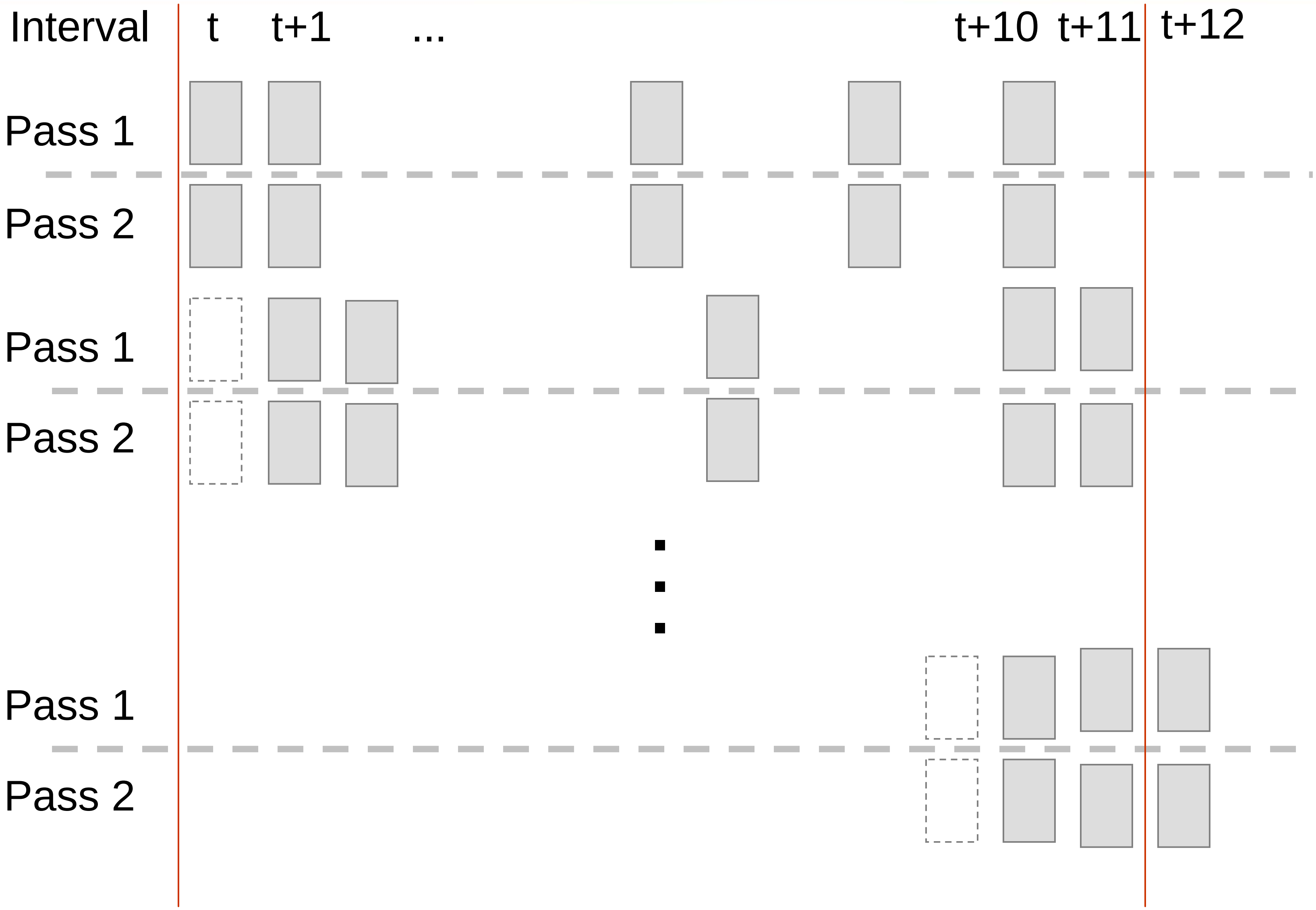
Pass 1 Realities

- Since certain constraints are approximations (e.g. linearization and ignoring constraints), dispatch and prices are only approximations.
- Resources <u>are not dispatched</u> according to the Pass 1 calculations.
- Shadow (incremental) prices are calculated by this pass for each critical interval but are not retained.
- The highest slice price in each of the Pass 1 critical intervals could be extracted.

Pass 2 Realities

- Uses more accurate constraint formulation.
- Resources are dispatched according to the Pass 2 calculations for the first interval only! Other (critical) intervals provide dispatch advisories
- Shadow (incremental) prices are calculated by this pass for all the critical intervals but are not retained (except for first interval).
- The highest slice price in each of the Pass 2 critical intervals could be extracted.

Graphical Illustration



Available Incremental Prices

- Incremental prices for all the critical intervals from pass 1 and 2 are obtained with each run of the MIO Real - Time Sequence.
  - note that incremental prices are calculated for the critical intervals and not all intervals.

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Available Incremental Prices Cont..

- For any interval (ending at time) t:
  - Prices will have been calculated by Pass 1 for the interval up to 11 times (e.g. remains a critical interval in all sequences) at times t, (t-5), (t-10),…, and (t-50).
  - We denote the above prices as P1(t,t), P1(t, t-5), …, and P1(t, t-50) respectively
  - Prices are also calculated by pass 2.
  - We denote the corresponding prices calculated by pass 2 as P2(t,t), P2(t, t-5), …, and P2(t,t-50) respectively

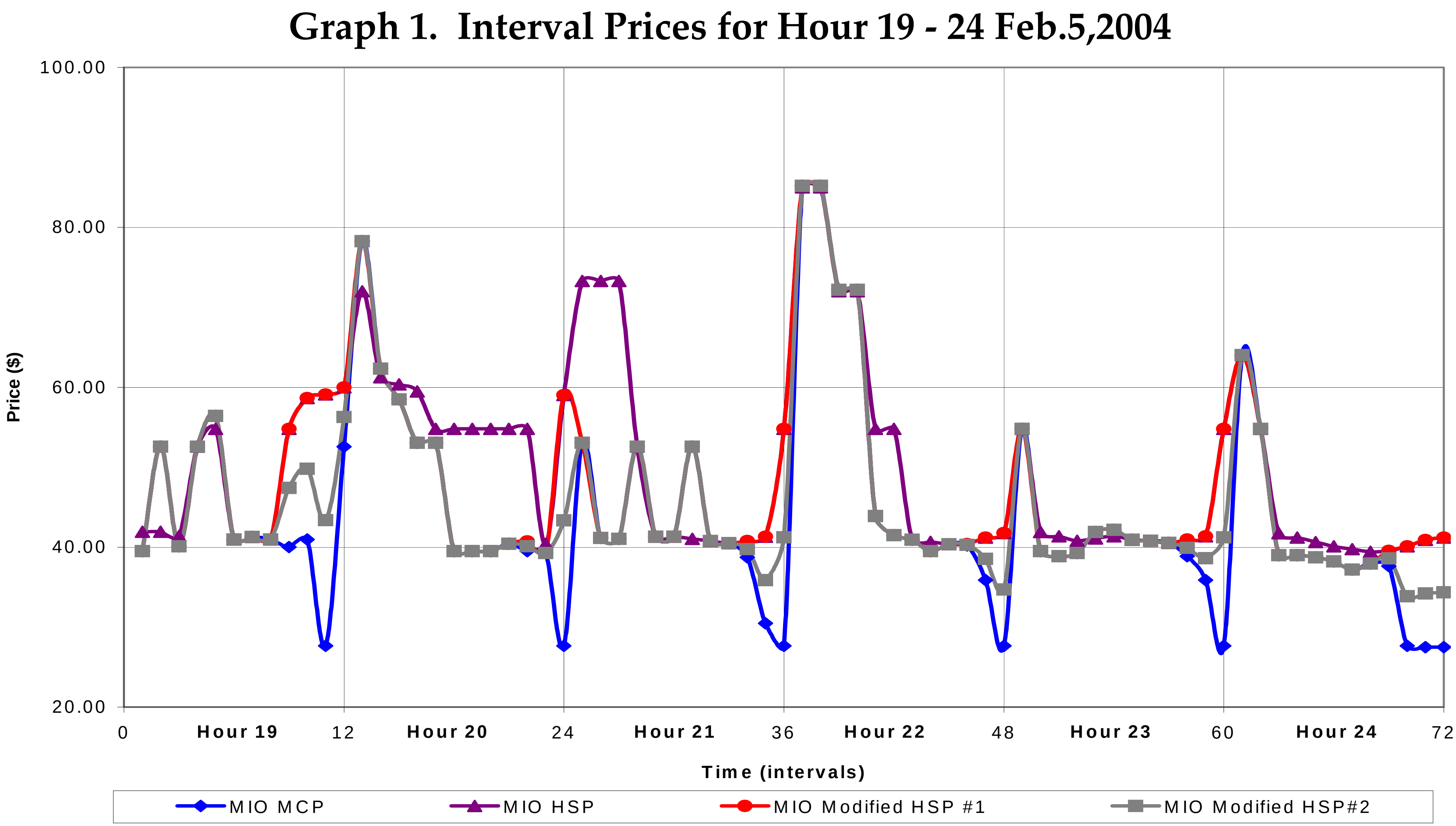
Presentation Outline

- Theoretical Perspective
- Current MIO Formulation and Prices
- **Simulation Results Illustration**

MIO Marginal Prices Illustration

- The following graph was included in the March 8, 2005 temporal presentation and will be used to illustrate the concept of MIO marginal prices.
- The graph displays the MIO pass 2 incremental price, or $P_2(t, t)$, which is labeled as MIO MCP in the graph.
- HSP and the two modified MIO prices (MHSP#1 and MHSP#2) are also included in the graph.
- During the period shown, demand is dropping by approximately 300 MW per hour.

MIO Marginal Prices Illustration Cont.



MIO Marginal Prices Illustration Cont.

» Consider the following MIO study period consisting of 11 intervals.

- Starting interval Hr.22 Interval 10.
- Ending interval Hr.23 Interval 8.

» MIO has to move resources around to more economically satisfy the demand at interval Hr. 23 Int. 1

» There are two cost considerations:

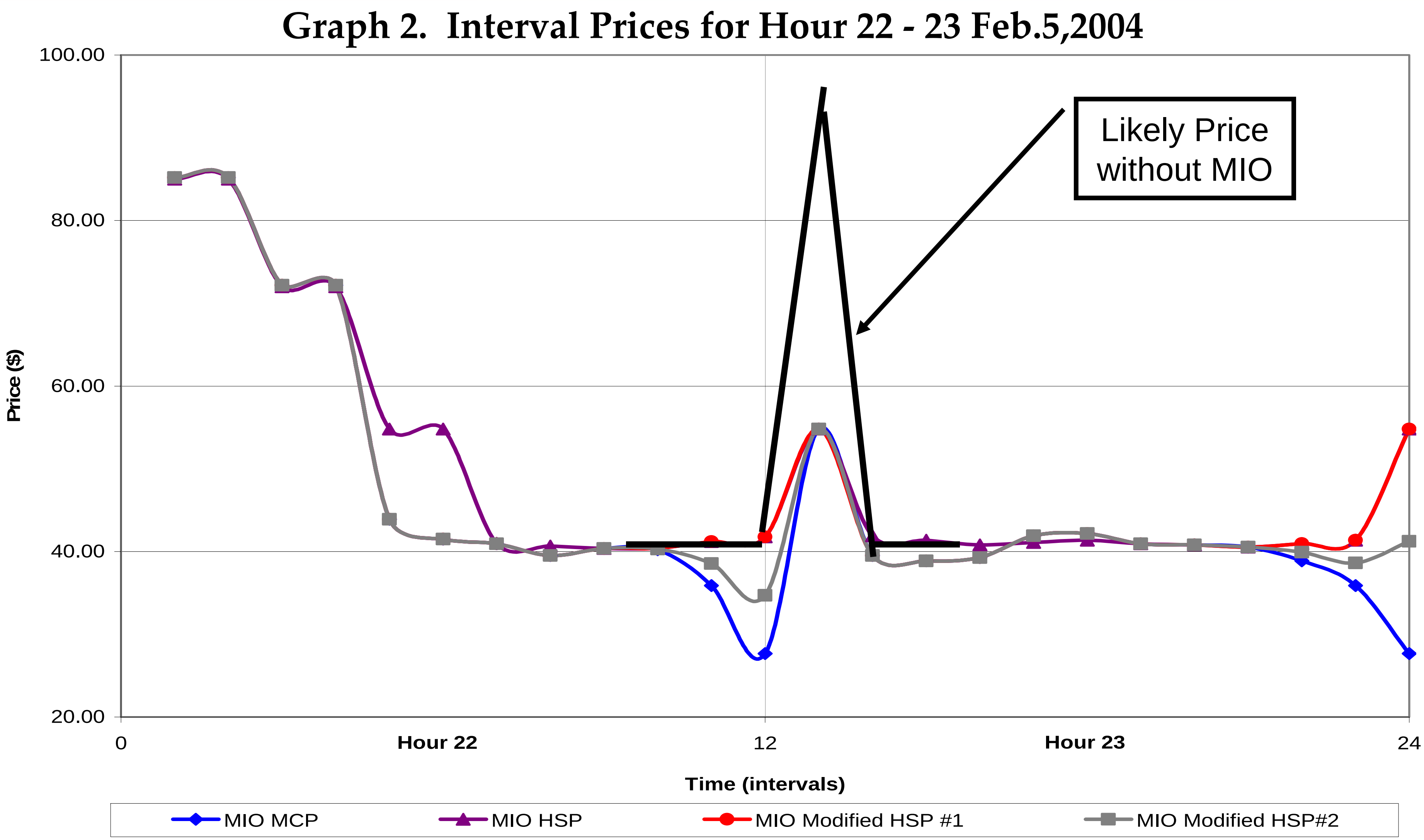
- Cost of ramping up higher priced units early so that they are able to meet demand at Hr.23 Int.1 and the corresponding ramp down of lower priced units.

MIO Marginal Prices Illustration Cont.

- The cost of retaining the ramped up units after Hr.23 Int.1 where they may not be required
  - due to possible ramp down limitations, an extra MW of ramp down has to come from a lower priced resource with additional ramp down capability with the assumption that the HSP resource is ramping down at its maximum capability.
  - addition cost of having such units in place of lower priced units after Hr.23 Int.1

» The additional costs associated with these two considerations must be factored into any decision on whether to ramp a unit up early or simply use a higher priced unit if one exists.

Price Components



Usage of Pass 1 Incremental Prices

- Prices calculated using inter-temporal optimization.
- Factors in all the costs incurred in the study period.
  - Includes the cost of the ramping up action before the interval, the incremental cost at the interval (myopic cost) and the cost that may be incurred as a result of ramp down limitations.
- For interval ending at time t.
  - The incremental price produced $P_1(t,t\text{-}50)$ will include the ramp up cost and the incremental (myopic) cost.
  - The ramp down cost will not be included because the intervals after it do not fall into the MIO study period.
  - As time passes, further ramp down limit costs are added into the incremental cost calculated: $P_1(t,t\text{-}45)$, $P_1(t,t\text{-}40)$, …., $P_1(t,t)$.
    - Occurs until all the ramp down limit cost is added to the prices.

Usage of Pass 1 Incremental Prices Cont.

- At the same time, the earlier ramp up costs incurred in the intervals before the MIO study period are dropped.
  - This occurs until all the ramp up cost that incurred is no longer included.
- Thus $P_1(t,t)$ will include the ramp down cost and the myopic cost but non of the earlier ramp up costs.

Usage of Pass 2 Incremental Prices.

» With the assumption of an accurate demand and interconnection schedule forecast, the myopic prices calculated in pass 2 will be equal to the myopic component of the prices calculated in pass 1.

» The myopic prices for an interval, t, will change slightly with each calculation as a result of factoring in ramp down limits in future intervals and their impact on schedules.

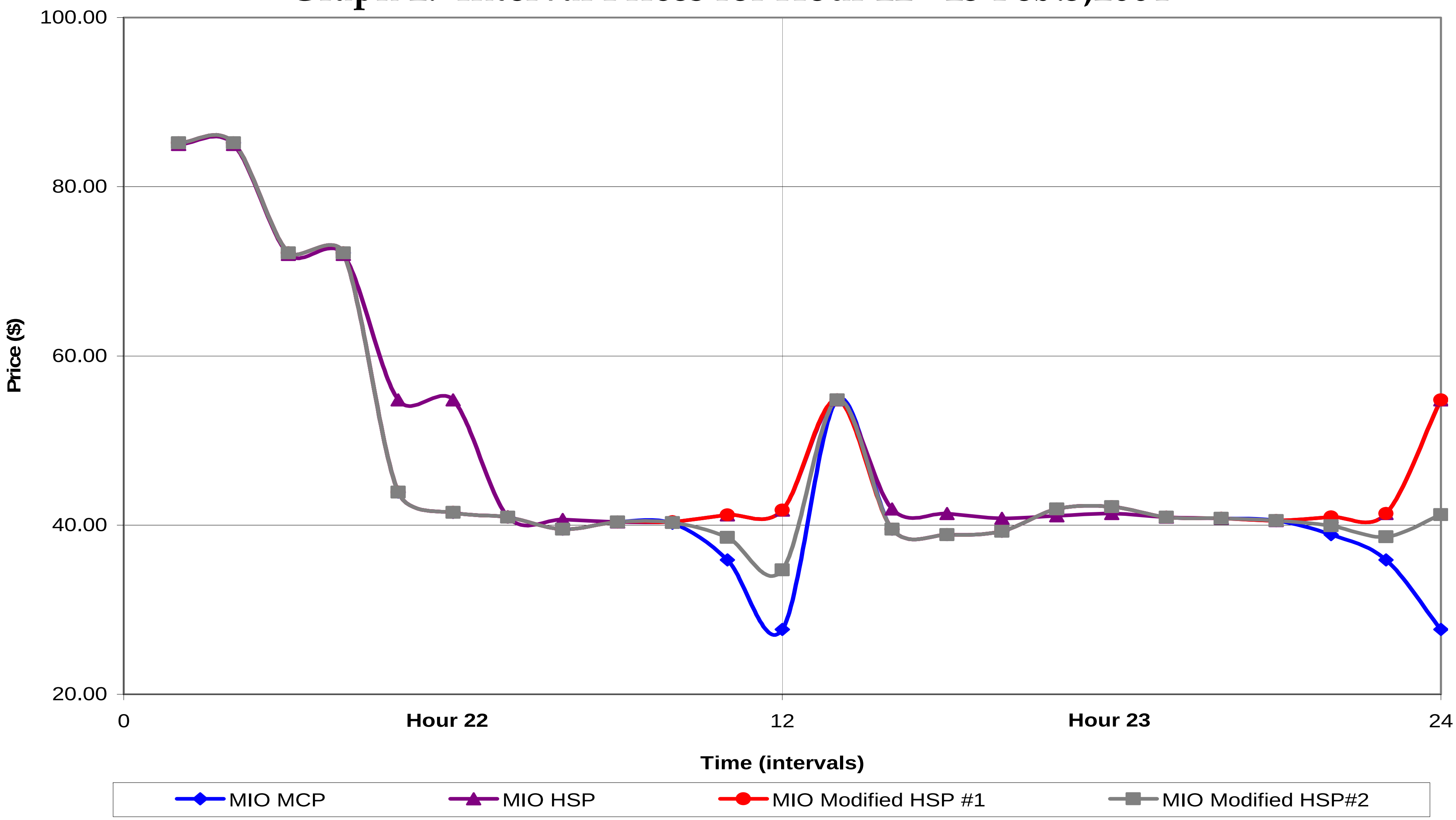
» These limits are ignored completely for the interval calculated at (t-50) and are gradually introduced as subsequent intervals are added to the MIO study period.

Usage of Pass 2 Incremental Prices Cont.

- The cost to the market of satisfying one addition MW at all intervals except Hr.23 int.1 will be the incremental price produced by the MIO pass 2 (individual interval optimization).

Hr.23 Interval 1

Graph 2. Interval Prices for Hour 22 - 23 Feb.5,2004



In Depth Look at Hr.23 Interval 1

» The cost of an additional one MW at Hr.23 Interval 1 is:

1) The myopic cost at the interval is the same as HSP except when joint optimization causes the incremental price to be higher than HSP.
   - Equal to the HSP base on the expectation that the most expensive lamination is being dispatched at this point.
   - Also valid if a load is setting the price.

2) The incremental cost of ramping an extra one MW in Hr.22 Int 10 - 12 is equal to:

$$\sum_{i=10}^{12}(HSP_i - MIO\,\mathrm{MCP}_\mathrm{i})$$

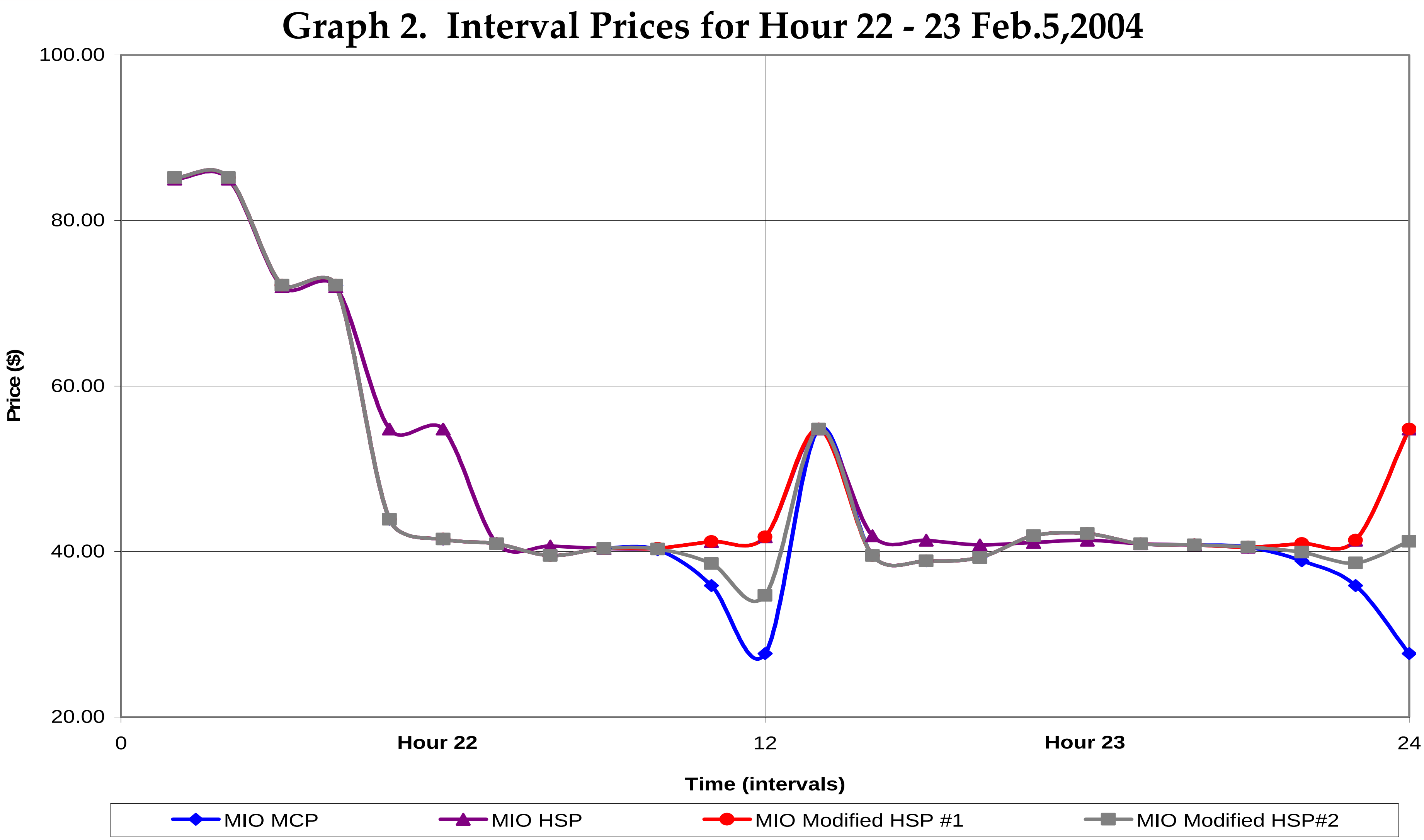
In Depth Look at Hr.23 Interval 1 Cont.

3) The incremental cost of ramping down the extra one MW Hr.23 Int 2 - 8 is defined by the upper limit of :

$$\sum_{i=2}^{8}(HSP_i - MIO\,\mathrm{MCP_i})$$

- The incremental cost will be equal to the sum if the most expensive unit at Hr.23 Int.1 is setting the HSP for all these intervals and the ramp down period falls within the MIO study period.

Allocation of Cost



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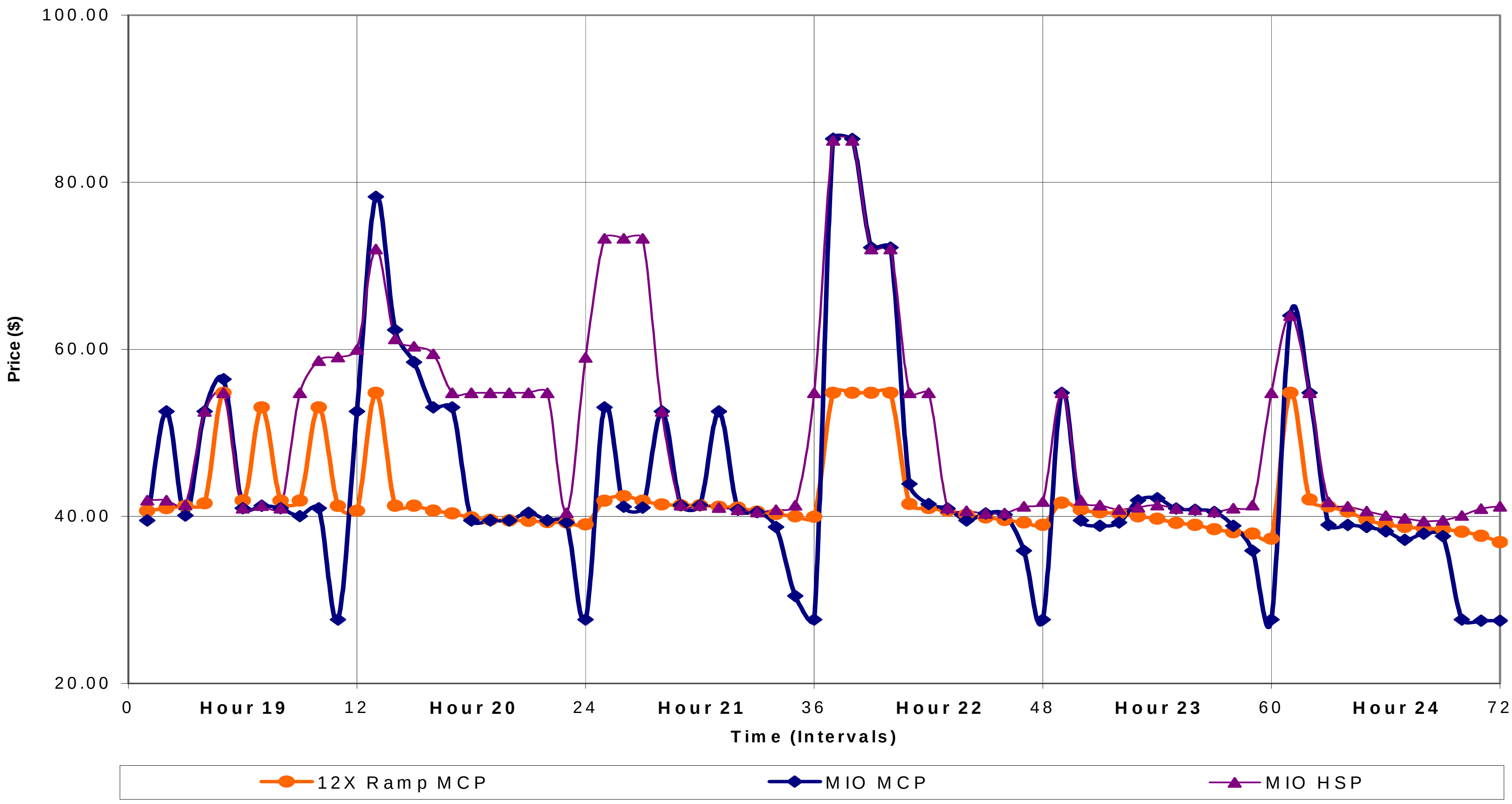
Allocation of Cost

Graph 3. More Interval Prices for Hour 22 - 23 Feb.5,2004



Marginal Price Limits

- Factoring the above and neglecting the demand variation over the study period, the upper limit for the marginal price for the period is the HSP.
- A lower limit for the marginal price within this period can be obtained by ignoring the last component of the marginal price at Hr.23 Int.1
  - Can be achieved if the units that are ramping down at their full offer ramp rate are excluded when calculating HSP.
  - Also prevents units, offered a high price to be dispatched off, from setting the HSP.

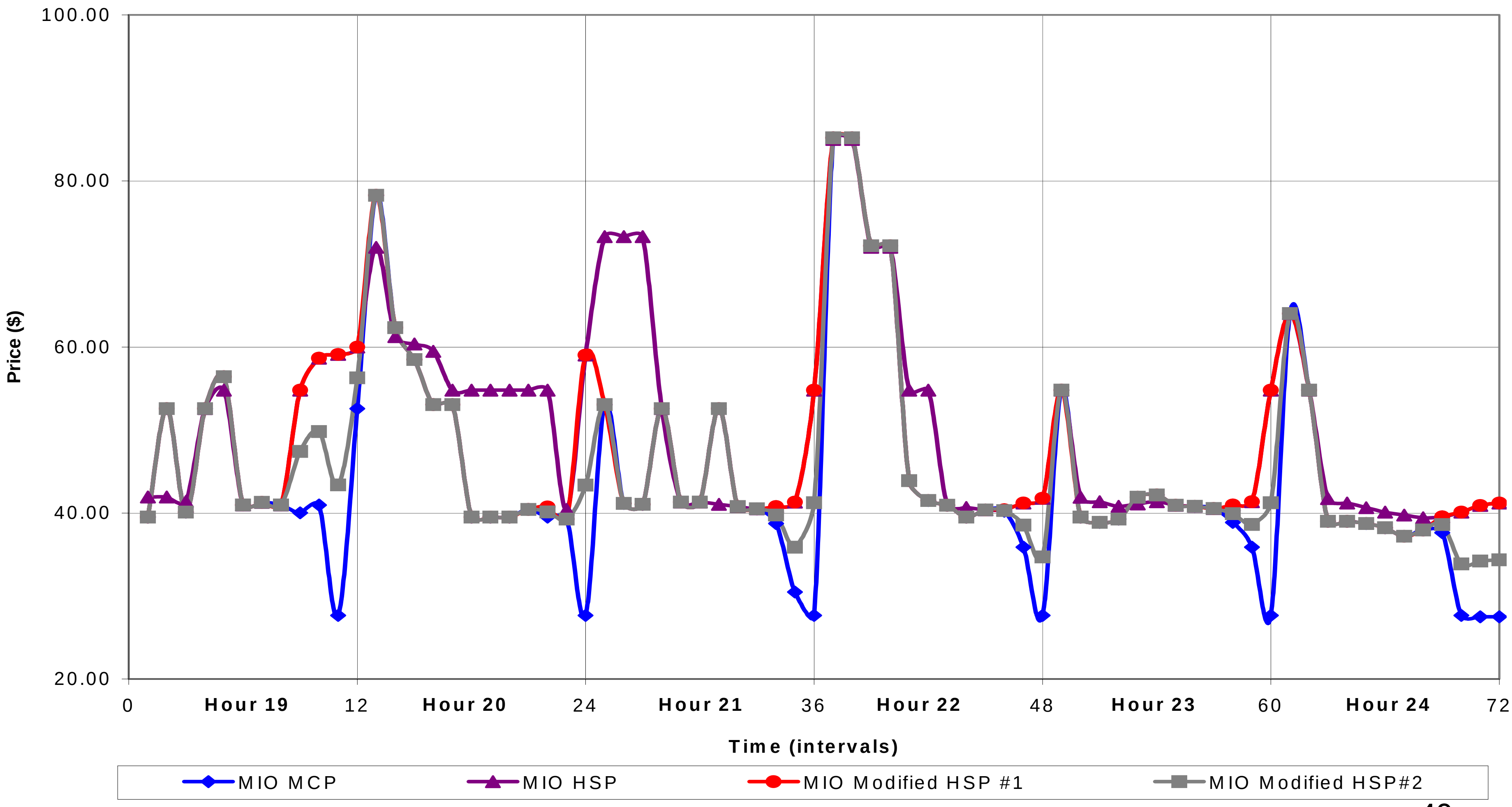
Consideration of Joint Optimization

» Under certain conditions, the joint optimization of energy and OR will result in an incremental price that is higher than the HSP for a given interval.

» This can be addressed by using the incremental price if it is higher than the HSP.

Modified HSP #1

Graph 1. Interval Prices for Hour 19 - 24 Feb.5,2004



Modified HSP #1

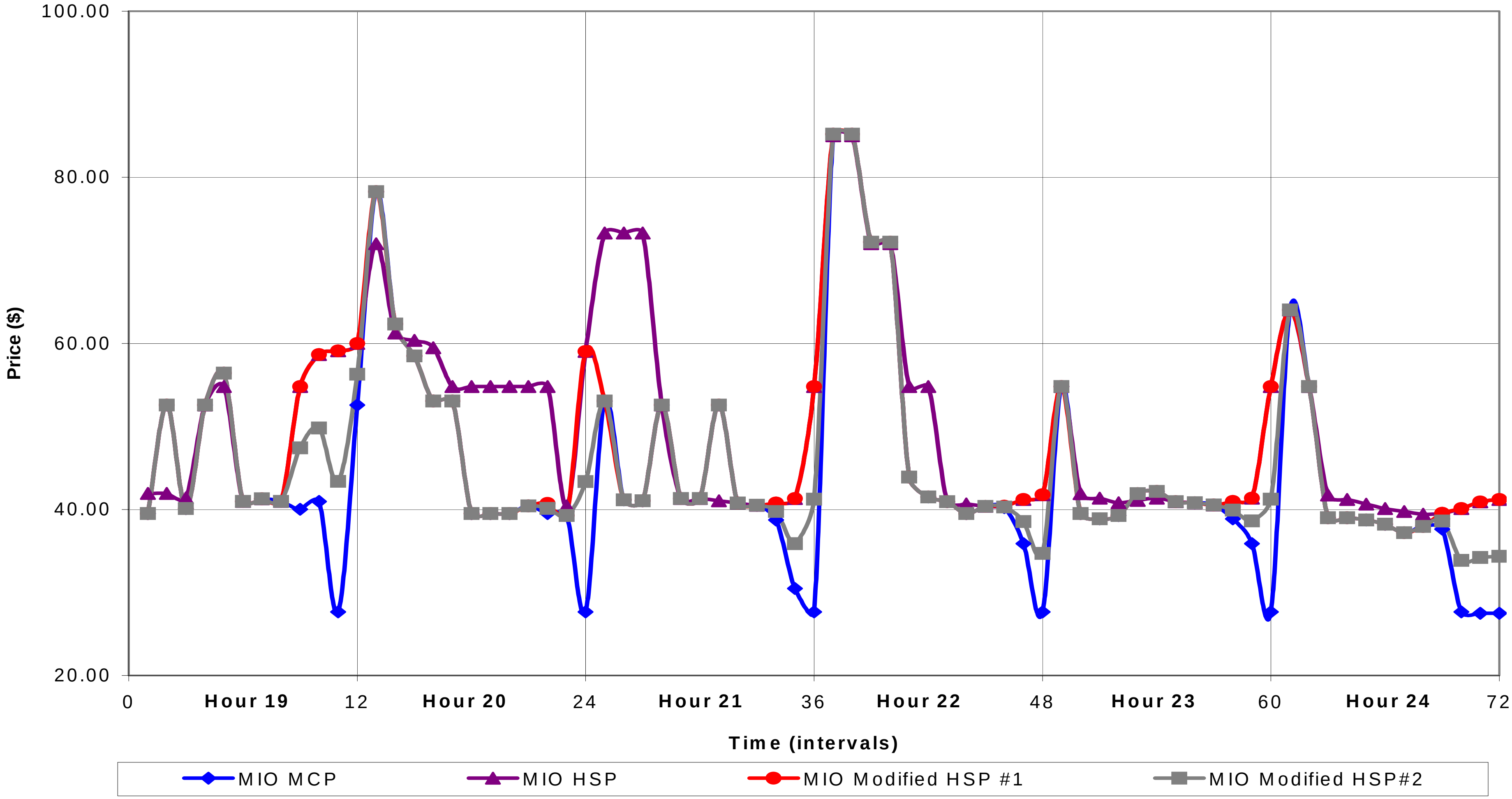
- MHSP#1 consists of ignoring units that are ramping down at their full offer ramp rate and the use of incremental prices if they are greater than the HSP.
- To capture the incremental cost of ramping down an extra one MW, MHSP#1 would need to be changed to use incremental prices calculated in Pass 1 (inter-temporal optimization) of MIO or $P_1(t,t)$.

Modified HSP#2

- MHSP#2 could be considered a compromise mid way between the incremental price and MHSP#1

Ramping for more than one interval

Graph 1. Interval Prices for Hour 19 - 24 Feb.5,2004



Findings

- In the above illustration, the ramp up/down contributes to the marginal price of Hr.23 Int.1 only.
- The logic is also valid when the ramp up/down contributes to more than one interval such as Hr.21 Int.10
- The ramp up cost can not be assigned to a specific interval.

Supplementary Slides

Example

- Assume two intervals with demand of 1200MW and 1300MW
- Three units are available
- First hydro-electric: capacity = 1000MW, price = $30 / MWh
- Fossil: capacity = 500MW, price = $40 /MWh, Ramp = 50 MW/ Interval
- second hydro-electric: capacity = 200 MW, price = $100 /MWh
- Myopic dispatch:
- Interval 1: First hydro-electric = 1000 MW, Fossil = 200 MW, Price=$40 /MWh
- Interval 2: First hydro-electric =1000 MW, fossil = 250 MW, Second hydro-electric = 50 MW, Price = $100/ MWh.

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Example

- MIO dispatch
- Interval 1: First hydro-electric = 950 MW, Fossil = 250 MW, Incremental price = $30 / MWh, HSP = $40 MW/ MWh
- Interval 2: First hydro-electric = 1000 MW, Fossil =300 MW, Incremental price = HSP = $40/ MWh.