



Issue 31 – MIO Pricing Methodology: Pricing Example

The following provides an illustrative example of the revenue impacts on the different market participants of the different pricing techniques identified under Issue 31. This example is illustrated in the figure at the end of this document. Operation in the steep part of the supply curve is represented by pricing G3 at \$80 per MWh. Operation in the relatively flat part of the supply curve is represented by pricing G3 at \$60 per MWh. Each of the three periods outlined in Figure 1 pertain to the **first period** of demand being less than or equal to the capacity of G1, the **second period** of demand being greater than the capacity of G1 and less than or equal to the combined capacity of G1+G2, and the **third period during** which demand exceeds the combined capacity of G1+G2. For the purposes of this example, we will assume that each period consists of five five-minute intervals. As, well, we will assume that the demand ramp up is greater than the ramp rate of G2, which is the marginal unit during the middle period. As all the pricing techniques produce approximately the same prices and dispatches when the demand is ramping down and when the demand ramp up rate is less than the sum of the ramp rate of all marginal units, there is no need to consider these cases here.

In determining the revenue impacts of different market participants per period, the following three equations are used:

$$\text{Profit for Generator} = \frac{5 \text{ intervals per period} * \text{average MW over the period} * (\text{MCP per MWh in the period} - \text{Offer Price per MWh in the period})}{12 \text{ intervals in an hour}}$$

$$\text{Constr.Off} = \frac{5 \text{ intervals}_{\text{per Period}} * (\text{average MW dispatched unconst.}_{\text{over the period}} - \text{average MW dispatched const.}_{\text{over the period}}) * (\text{MCP}_{\text{in the Period}} \text{ per MWh} - \text{Offer Price}_{\text{in the Period}} \text{ per MWh})}{12 \text{ intervals in an hour}}$$

$$\text{Constr.On} = \frac{5 \text{ intervals}_{\text{per Period}} * (\text{average MW dispatched const.}_{\text{over the period}} - \text{average MW dispatched unconst.}_{\text{over the period}}) * (\text{Offer Price}_{\text{in the Period}} \text{ per MWh} - \text{MCP}_{\text{in the Period}} \text{ per MWh})}{12 \text{ intervals in an hour}}$$

It may be helpful to refer to the above 3 equations when reading through the mathematical explanations of how the profit for each generator in each scenario is calculated. Furthermore, the figure on the last page of this paper will be useful in understanding how each value in the calculations was determined. Further, it should be noted that “profit” is represented by the difference between the generator’s offer price and the market clearing price.



A. Operation on the flat part of the supply curve:

First we will consider the case when we are operating on the relatively flat part of the supply curve. MIO will not ramp any of the generating units early because doing so will not yield a more “cost” effective dispatch over the period of interest. Consequently MIO will produce the same prices and dispatches, as is the case under 1X ramp. The MCP prices produced by the different pricing techniques are shown in the figure. The revenue of each generator is as follows:

12X ramp:

Total Profit for G1 = $1/12 (5 \times 50 \times \$10 \text{ profit for second period} + 5 \times 50 \times \$20 \text{ profit for third period}) = \625.00

Total Profit for G2 = $1/12 (5 \times 37.5 \times \$10 \text{ profit for third period} + 5 \times 12.5 \times \$10 \text{ constrained off for third period}) = \208.33

Total Profit for G3 = $\$0 \text{ (constrained on payment for second period of } 1/12 (5 \times 12.5 \times \$10)) = \$52.08$

The constrained on/off payment will result in an average uplift of \$10/6 per MWH in the second period and \$1 per MWH in the third period.

1X ramp and MIO:

(**Note:** The results are the same regardless of whether one uses MIO incremental or MIO highest slice as the pricing technique. Recall that MIO Incremental reflects the price of the next available MWh not the price of the most expensive generator in the interval. MIO Highest Slice reflects the price of the highest generator on the stack of the interval. Please refer to the examples further into this paper for an illustration of how MIO Incremental and MIO Highest Slice prices are calculated.)

Total Profit for G1 = $1/12 (5 \times 50 \times \$20 \text{ profit for second period} + 5 \times 50 \times \$20 \text{ profit for third period}) = \833.33

Total Profit for G2 = $1/12 (5 \times 12.5 \times \$10 \text{ profit for second period} + 5 \times 37.5 \times \$10 \text{ profit for third period}) = \208.33

Total Profit for G3 = $\$0$

There are no constrained on/off or uplift payments.

Under all pricing options G2 and G3 are getting the same payment. Under the 1X ramp and MIO pricing options, G1 is getting a higher payment during the second period. Loads consuming in the second period will be paying more under the 1X ramp and MIO.

	12X Ramp	1X Ramp and MIO
Profit for Generator 1	\$625.00	\$833.33
Profit for Generator 2	\$208.33	\$208.33
Profit for Generator 3	\$0.00	\$0.00

Table 1. Summary Table for Section A. Operation on the flat part of the supply curve.

B. Operation on the steep part of the supply curve:

Now we consider the case when we are operating on the steep part of the supply curve. MIO will ramp up unit G2 early to avoid running G3 in the second period. The MCP prices are shown below. The revenue of each generator is as follows:

12X ramp:

$$\text{Total Profit for G1} = 1/12 (5 \times 37.5 \times \$10 \text{ profit for second period} + 5 \times 12.5 \times \$10 \text{ constrained off for second period} + 5 \times 50 \times \$40 \text{ profit for third period}) = \$1041.67$$

$$\text{Total Profit for G2} = 1/12 (5 \times 50 \times \$30 \text{ profit for third period}) = \$625.00$$

$$\text{Total Profit for G3} = \$0$$

G2 will receive a *constrained on payment for the first period* of $1/12(5 \times 12.5 \times \$10) = \$52.08$.

The constrained on/off payment will result in an average uplift of \$5 per MWH in the first period and \$10/6 per MWH in the second period.

1X ramp:

$$\text{Total Profit for G1} = 1/12 (5 \times 37.5 \times \$40 \text{ profit for second period} + 5 \times 12.5 \times \$40 \text{ constrained off for second period} + 5 \times 50 \times \$40 \text{ profit for third period}) = \$1666.67$$

$$\text{Total Profit for G2} = 1/12 (5 \times 37.5 \times \$30 \text{ profit for second period} + 5 \times 50 \times \$30 \text{ profit for third period}) = \$1093.75$$

$$\text{Total Profit for G3} = 0$$



G2 will receive a *constrained on payment for the first period* of $1/12(5 \times 12.5 \times \$10) = \$52.08$.

The constrained on/off payment will result in an average uplift of \$5 per MWH in the first period and \$40/6 per MWH in the second period.

MIO incremental:

Total Profit for G1 = $1/12 (5 \times 50 \times \$40 \text{ profit for third period}) = \833.33

Total Profit for G2 = $1/12 (5 \times 50 \times \$30 \text{ profit for third period}) = \625.00

Total Profit for G3 = \$0

G2 will need to be paid $1/12(5 \times 12.5 \times \$10) = \$52.08$ in the first period and $1/12(5 \times 37.5 \times \$10) = \$156.25$ in the second period to hold him whole.

The payment to G2 will result in an average uplift of \$5 per MWH for the first and second periods.

MIO highest slice:

Total Profit for G1 = $1/12 (5 \times 12.5 \times \$10 \text{ profit for first period} + 5 \times 37.5 \times \$10 \text{ profit for second period} + 5 \times 50 \times \$40 \text{ profit for third period}) = \1041.67

Total Profit for G2 = $1/12 (5 \times 50 \times \$30 \text{ profit for third period}) = \625.00

Total Profit for G3 = 0

There are no other payments or uplift.

If we compare the revenues produced by the 1X ramp and MIO pricing techniques when operating in the steep part of the supply curve, we will find out that:

- The 12X ramp and the MIO highest slice produce the same revenues
- The MIO incremental revenue for G1 is less than the 12X ramp revenues. Revenue for the other generators are the same.
- The 1X ramp revenue is very high compared to the 12X ramp.



Summarizing the results from the two cases, we get the following:

- 1X ramp will produce higher prices than the 12X ramp in both cases.
- MIO highest slice will produce the same price as the 12X ramp during operation in the steep part of the supply curve and will produce higher prices during operation in the relatively flat part of the curve. Overall the expectation is that the average price produced by the MIO highest slice will be higher than the 12X ramp.
- MIO incremental will produce lower prices than the 12X ramp during operation in the steep part of the supply curve and will produce higher prices during operation in the relatively flat part of the curve. Overall the expectation is that the average price produced by the MIO incremental will be the closest (slightly higher than) to the 12X ramp.

	12X Ramp	1X Ramp	MIO Incremental	MIO Highest Slice
Profit for Generator 1	\$1041.67	\$1666.67	\$833.33	\$1041.67
Profit for Generator 2	\$625.00	\$1093.75	\$625.00	\$625.00
Profit for Generator 3	\$0.00	\$0.00	\$0.00	\$0.00

Table 2. Summary Table for Section B. Operation on the steep part of the supply curve.



Ramp Up

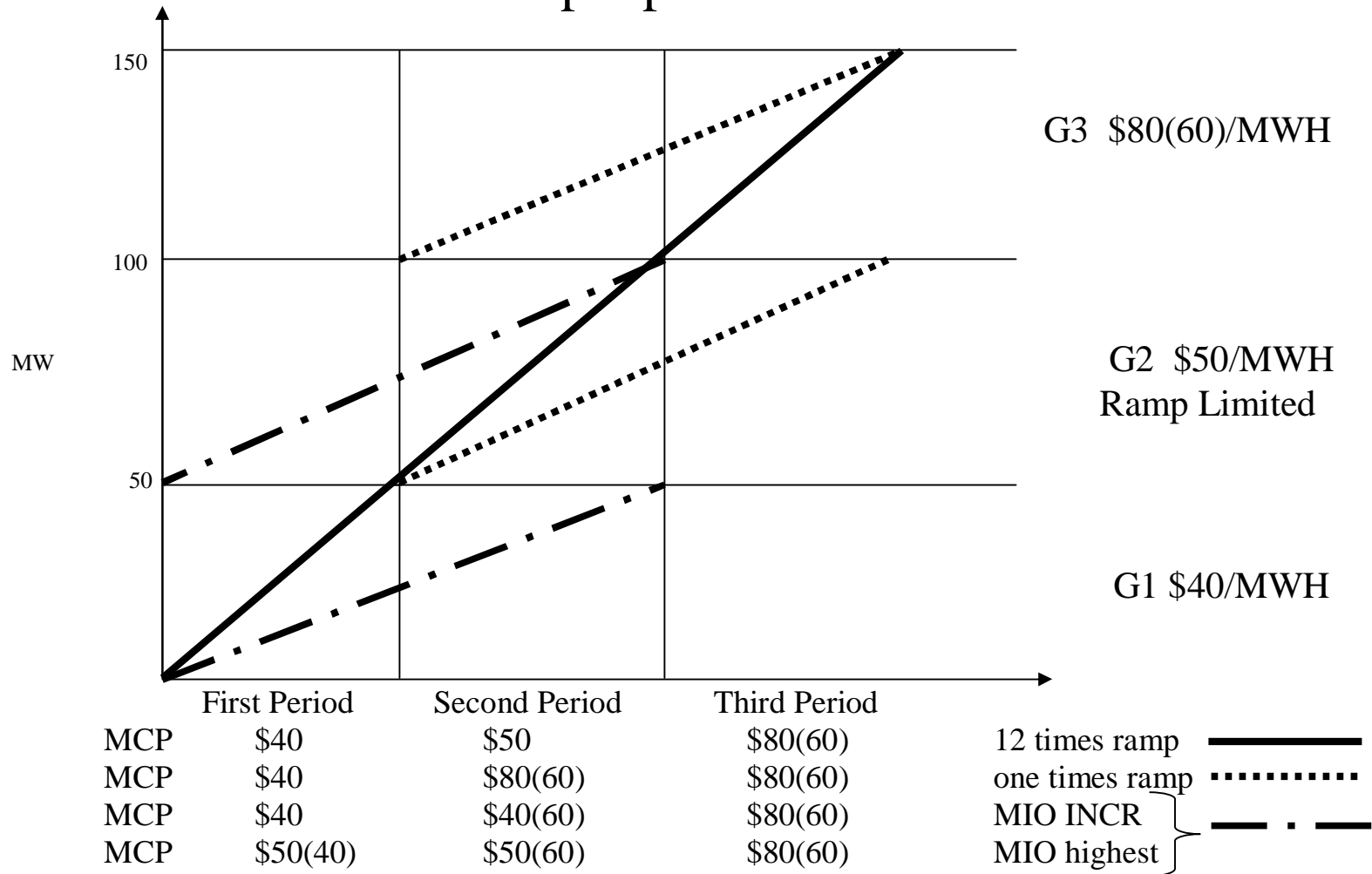


Figure 1. Example of a Demand Curve – contains two different examples: when the offer price of G3 is \$80 and when the offer price of G3 is \$60. Whenever there are two values (one within parentheses and one without) then the price within parentheses pertains to the case when the offer price of G3 is \$60. For the cases where only one value exists, it implies that this value is the same for both the \$60 case and the \$80.