

Part of the rationale for creating competitive energy markets in Ontario was to improve efficiency in the electricity sector. When we evaluate market evolution proposals, improved market efficiency is a key aspect in the decision making process. It is important that the IESO and stakeholders have a common understanding of efficiency when discussing the market and its evolution.

There are three key concepts of efficiency that are relevant to the electricity industry:

- (i) Productive Efficiency
- (ii) Allocative Efficiency
- (iii) Dynamic Efficiency

The first part of this memo offers a working definition for each of these concepts of efficiency. Productive efficiency is the concept of efficiency that is most often used in engineering or business application and hence the most understood of the three concepts. Achieving productive efficiency is also an implicit condition of achieving allocative efficiency. For these two reasons it makes sense to establish a working definition for productive efficiency. Allocative efficiency and dynamic efficiency are the concepts of efficiency that are most likely to be relevant in market pricing issues. As a result, alternative definitions for allocative and dynamic efficiency are provided for further clarification. The second part of this memo provides several stylized examples of potential inefficiencies to further illustrate allocative and dynamic efficiency concepts.

## **Efficiency and the Role of Price Signals**

In a market context, price signals direct the decisions of the diverse set of suppliers and consumers. The individual decisions of these participants determine the eventual market outcome and hence the efficiency of this outcome. Efficient outcomes are more likely when the price signals directing the suppliers' and consumers' decisions:

- accurately reflect the incremental cost of supplying another MW of energy or the incremental benefit from consuming another MW of energy, and
- are known by both suppliers and consumers, who are able to respond to them.

## Economic Efficiency Defined

### **1. Productive Efficiency**

Productive efficiency deals with how a product is produced. It is more focused on the production process itself than whether or not the good should have been produced.

#### Working definition:

Productive efficiency is defined as using the least amount of resources to produce a given good or service. In other words, output is being produced at the lowest possible unit cost.

Productive efficiency implies firms are using:

- The least costly labour capital and land inputs;
- The best available technology;
- The best production processes;
- Exploiting all potential economies of scale; and
- Minimize the wastage of resources in their production processes

### **2. Allocative Efficiency<sup>1</sup>**

A common definition of efficiency is that something is done well, without wasted energy. Allocation on the other hand deals with setting things aside or assigning certain resources to certain tasks.

#### Working Definition:

Allocative efficiency is the market condition whereby resources are allocated in a way that maximizes the net benefit attained through their use. A market will be allocatively efficient if:

- (1) Output is produced by the lowest cost producers
- (2) Output is consumed by those most willing to pay for it and only when its value to the consumer is at least as great as the incremental cost of its production

#### Alternative Definition 1:

Allocative efficiency occurs when no resources are wasted – when no one can be made better off without making someone else worse off. (Economics: Canada in the Global Environment, Parkin and Bade, 2000).

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<sup>1</sup> Allocative efficiency is also sometime referred to as static efficiency or short-term efficiency.

### Alternative Definition 2:

An industry or market is allocatively efficient when the social marginal benefit of the last unit produced equals its social marginal cost. If industry output is allocatively inefficient, then units of output are not produced for which consumers are willing to pay more than the social marginal cost of production or units are produced for which consumers are not willing to pay the social marginal cost of production. (Industrial Economics: A Strategic Approach, Church and Ware, 2001)

### Alternative Definition 3:

Allocative efficiency in a given market involves comparing the cost of producing an extra unit – marginal cost - with the benefit gained from its consumption – marginal benefit. If marginal cost of an extra unit is less than the marginal benefit derived from its consumption, then it makes sense to increase production. If marginal cost is more than the marginal satisfaction gained from consumption then it makes sense to reduce production and release resources for alternative, 'better' uses. Identifying allocative efficiency involves comparing the cost of producing an extra unit with the benefit gained from its consumption. (Wikipedia A Free Encyclopedia [http://www.woodgreen.oxon.sch.uk/economics/allocative\\_efficiency.htm](http://www.woodgreen.oxon.sch.uk/economics/allocative_efficiency.htm))

## **3. Dynamic Efficiency**

Time is the central difference between allocative and dynamic efficiency. Allocative efficiency deals with the most efficient use of resources at a given point in time. Dynamic efficiency on the other hand deals with the evolution of a more efficient mix of resources for the market over time.

### Working definition:

Dynamic efficiency relates to efficient technology choice and timely and efficient capacity investment decisions both on the supply side and the demand side of the industry.

Dynamic efficiency requires that proper incentives exist to make long-term decisions, such as those about investment and the introduction of new products and services. Dynamic efficiency also requires that the effects of decisions in one period be taken into account for future periods.

### Alternative Definition 1:

Efficient change in an economy, particularly the most efficient use of resources over time, the best rate of technological change, and the most efficient rate of growth (Introduction to Microeconomics, Blomqvist et al 1994).

Alternative Definition 2:

"Competition from the new commodity, the new technology, the new source of supply, the new organization ... competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives. Dynamic efficiency involves innovation, and innovation involves risk." (Joseph Schumpeter, *Capitalism, Socialism and Democracy* 84 (1942))

## Examples of Allocative Inefficiencies

The following two examples are provided to illustrate the concept of allocative efficiency. We choose to illustrate the concept of allocative efficiency by showing how under some circumstances, a uniform pricing system could lead to allocative inefficiencies. In this regard, the examples serve a secondary purpose in that they can be used in our later discussions of the efficiency considerations for moving to a locational marginal pricing system.

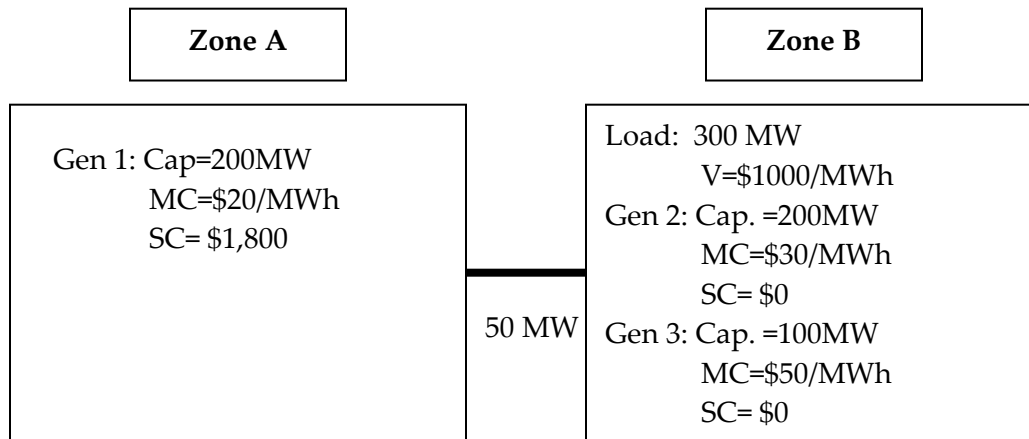
In both examples the more efficient outcome results in wealth transfers, the first example from loads to generators and the second example the converse from generators to loads. Often changes to market mechanisms intended to increase allocative efficiency result in winners and losers from the status quo. Temporary mechanisms can be introduced to smooth the transition of a change. The Global Adjustment may offer a mechanism for reallocating wealth transfers. Grandfathering transmission rights to certain consumer groups in different regions in the province may represent a transition mechanism for a change to locational pricing.

Each example adopts the following structure. First, the general assumptions of the market structure (generation mix, load and transmission) are outlined. Second, the efficient allocation is determined and described. Following this, we provide an illustration of how a uniform pricing regime could induce an allocatively inefficient outcome and how a locational marginal pricing regime could correct the inefficiency.

### *Example 1: Output is not produced by the cheapest suppliers*

In this example, there are two zones, Zone A and Zone B, with a 50MW transmission line connecting the two zones. Figure 1 illustrates the load and generation mix in each zone.

**Figure 1: Two Zone Model with Start-up/Speed-no-load Costs**



*Zone B Load*

There is a 300 MW dispatchable load located in Zone B. The load is an industrial consumer that uses 1 MW of electricity to produce 1 unit of a product each hour that it will sell in its own market, up to a capacity of 300 units per hour. After accounting for all other input costs, Load B can pay up to \$1000/MWh for electricity and achieve a positive rate of return. The load values electricity consumption at \$1000/MWh in this example.

*Zone A & B Generators*

Gen 1 located in Zone A has the lowest marginal cost of production. However, when it produces, it also incurs a fixed start-up cost and fuel costs related to speed-no-load of \$1,800 per hour. In Zone B there are two generators each with higher marginal costs than Gen 1 but with no start-up or speed-no-load costs.

**Allocative Efficient Outcome**

Allocative efficiency is about maximizing the net benefit attained from the use of available resources. It involves comparing the cost of producing an extra unit – marginal cost - with the benefit gained from its consumption – marginal benefit and increasing the amount produced until the marginal benefit is equal to the marginal cost.

In our example, the marginal benefit of consumption is \$1000 for each of the first 300 MW of consumption.<sup>2</sup> It will be efficient to supply this load with 300 MW as long as the marginal cost of producing each MW is less than \$1000. The marginal cost for each unit of output of

<sup>2</sup> Given that the Load is with a capacity constraint of 300 units of output, the marginal benefit if consuming the 301<sup>st</sup> unit of electricity is 0.

Gen 2 and Gen 3 is \$30 and \$50 respectively. Given that there is a one-time fixed cost that must be incurred for Gen 1 to produce anything at all, the measure for considering the relative efficiency of its production is average incremental cost (AIC). The average incremental cost of Gen 1 producing 50 MW (the most that Gen 1 can produce given the transmission constraint) is  $AIC = (\$1,800 + \$20 \times 50\text{MW}) / 50\text{MW} = \$56\text{MW}$ . Thinking about it from this perspective, it cost \$56/MWh to get the first 50 MW from Gen 1, but only \$30/MWh from Gen 2. Given the fixed start-up\speed-no-load costs and transmission constraint, Gen 2 is the relatively lower cost generator. Similarly, Gen 3, with marginal cost of \$50/MWh is also relatively lower cost than Gen 1. The efficient outcome is therefore to have Gen 1 not to start and avoid incurring the fixed cost of \$1,800.

The least costly way to meet the 300 MW of load is to have Gen 2 produce the first 200 MW at a marginal cost of \$30/MWh and Gen 3 produce the next 100 MW. The net benefit from each of the MW supplied from Gen 2 is (\$1000-\$30) for a total net benefit of  $(\$1000-\$30) \times 200\text{MW} = \$194,000$ . The net benefit from each MW supplied from Gen 3 is (\$1000-\$50) for a total net benefit of  $(\$1000-\$50) \times 100\text{MW} = \$95,000$ . The total net benefit from this allocation is \$289,000. No other allocation of resources can be found that would provide a higher net benefit.

Let's look at what would happen under both uniform and locational pricing regimes.

### **Uniform Pricing Regime Results**

For this example we assume that all generators bid competitively (i.e., the higher of their average avoidable cost or their marginal cost) and abstain from exercising market power.

It is worthwhile to first consider the incentives for Gen 1 to offer at its marginal cost in a uniform pricing regime. First, the profit for Gen 1 is calculated as:

$$\begin{aligned} \text{Profit} &= \text{Energy Revenue} + \text{Uplifts} - \text{production cost} \\ &= \text{HOEP} \times \text{DQSI} + (\text{Offer Price} - \text{HOEP}) \times (\text{DQSI} - \text{MQSI}) - \$20 \times \text{DQSI} - \$1,800^3 \end{aligned}$$

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<sup>3</sup> DQSI = Constrained Quantity and MQSI = Unconstrained Quantity

Gen 1 will only operate if it is able to cover both its marginal cost of production plus its fixed start/speed-no-load costs (i.e., earn a non-negative profit). In a uniform pricing regime, if Gen 1 offers all of its capacity at its marginal cost of \$20, which is lower than the marginal cost of either of the other two generators, it will certainly be scheduled in the unconstrained sequence for the entire capacity. Given the 50 MW transmission constraint however, in the constrained sequence it will only be scheduled for 50 MW. Therefore, Gen 1 will be constrained off for 150MW. Using the profit function above it will be profitable for Gen 1 to offer its capacity at marginal cost, \$20, and start its unit only if:

$$\text{Profit} = \text{HOEP} \times 50 + (\$20 - \text{HOEP}) \times (-150\text{MW}) - \$2,800 > 0.$$

This can be rewritten to show that Gen 1 will offer at marginal cost if  $\text{HOEP} > \$29$ . Given that the marginal cost of the other two generators is greater than \$29, this will certainly be the case. Therefore, Gen 1 can offer at its marginal cost and be assured to cover its fixed cost. It covers these fixed costs largely through the constrained off payment that it earns.

Hence, assuming that each generator offers at marginal cost, the uniform pricing regime unconstrained sequence which ignores the 50 MW transmission constraint between Zone A and Zone B, schedules Gen 1 for 200 MW and Gen 2 for 100 MW to satisfy the 300 MW load. The HOEP is set by Gen 2 at \$30/MWh.

The constrained schedule recognizes the 50 MW transmission limit. Gen 1 is scheduled for only 50MW in the constrained sequence – it is constrained off by 150 MW. Gen 2 is scheduled for 200 MW (constrained on for 100 MW) and Gen 3 is scheduled for 50MW (constrained on). The shadow prices are \$20 in Zone A and \$50 in Zone B.

The welfare of the load and each generator under the uniform pricing regime is outlined in Table 1 below.

**Table 1: Welfare Cost of Production under Uniform Pricing Regime**

<b>Participant</b>	<b>Cost of Production</b>	<b>Welfare</b>
<b>Gen 1</b>	MC x Output plus SC = \$20x50MW + \$1,800 = \$2,800	Energy revenue plus CMSC less production cost = \$30x50MW + (\$20-\$30)x150MW - \$2,800 = \$200
<b>Gen 2</b>	MC x Output plus SC = \$30x200MW + \$0 = \$6,000	Energy revenue plus CMSC less production cost = \$30x200MW + (\$30-\$30)x100MW - \$6000 = \$0
<b>Gen 3</b>	MC x Output plus SC = \$50x50MW + \$0 = \$2,500	Energy Revenue plus CMSC less production cost = \$30x50MW + (\$50-\$30)x50MW - \$2,500 = \$0
<b>Load</b>		Value of consumption less energy cost less uplift \$1000x300MW - \$30x300MW - (\$10x150MW + \$20x50MW) = \$288,500
<b>Total</b>	= \$11,300	= \$288,700

In the uniform pricing regime, the total welfare or net benefit in the province is \$288,700 and the total cost of electricity production (total value of resources used) is \$11,300. There is an allocative inefficiency that occurs in this example as a result of Gen 1 producing. Gen 1 is the highest cost supplier after accounting for start-up costs and transmission constraints and yet it was scheduled to produce. When we compare the net benefit of the efficient allocation to the net benefit of the allocation under uniform pricing, the inefficiency (deadweight loss) induced by uniform pricing is \$289,000-\$288,700=\$300

**Locational Marginal Pricing Regime Results**

A locational marginal pricing regime (LMPR) would induce a more efficient outcome in this example. Under a LMPR, the transmission constraint is considered in the scheduling of resources and in the price determination process. In the LMPR, there are no CMSC payments and prices in the two zones will be different if congestion on the transmission line occurs.

Note that in a LMPR, if Gen 1 is to produce, the most that it will sell is 50 MW. It will not receive CMSC payments for perceived lost opportunity cost at the HOEP. It will only produce if it is paid a locational price (P) for the 50 MW that allows it to cover all of its costs. That is:

$$\text{Profit Gen 1} = P \times 50\text{MW} - \$20 \times 50 - \$1,800$$

This implies it must receive a price no less than \$56/MWh which is its average incremental cost. In a LMPR, Gen 1 will offer at \$56/MWh.<sup>4</sup> Gen 2 and Gen 3 will continue to offer at their respective marginal costs.

Based on these offers, Gen 2 will be scheduled for 200 MW, and Gen 3 will be scheduled for 100 MW. The price in both zones will be set by the Gen 3 offer of \$50 (the value of another MW based on the offers in each zone is \$50). Table 2 outlines the welfare of each participant and the production cost incurred.

**Table 2: Welfare and Cost of Production under Locational Regional Pricing**

Participant	Cost of Production	Welfare
<b>Gen 1</b>	MC x Output less SC =\$0	Energy revenue less production cost =\$0
<b>Gen 2</b>	MC x Output less SC =\$30x200MW-\$0 =\$6,000	Energy revenue less production cost =\$50x200MW -\$6,000 =\$4000
<b>Gen 3</b>	MC x Output less SC =\$50x100MW-\$0 =\$5,000	Energy Revenue less production cost =\$50x100MW-\$5,000 =\$0
<b>Load</b>		Value of consumption less energy cost less uplift \$1000x300MW - \$50x300MW =\$285,000
<b>Total</b>	=\$11,000	=\$289,000

Under a LMPR, Gen 3 produces an additional 50 MW to meet the load instead of Gen 1. Having Gen 3 produce the additional 50 MW of supply instead of Gen 1 reduces the overall cost of supplying the 300 MW load. The overall production cost falls by \$300 while the overall welfare or net benefit realized across the entire province increases by \$300. In this example, LMP leads to the allocative efficient outcome. LMP induces an outcome that avoids the wasteful use of resources and this resource savings provides more overall welfare for the province as a whole.

While the LMPR produces a more efficient outcome, relative to the uniform pricing regime, it also creates “winners” and “losers.” The winner is Gen 2 who now earns a profit of \$4000. This is the “economic rent” that it earns for its relative efficiency as a producer. The losers are Gen 1 and the Load. Gen 1 loses profits of \$200. Although it avoids the uplift charge, the Load is made worse because it must pay a higher energy charge. The load’s welfare declines by \$3500. If there was a transition mechanism that would allow for a transfer of wealth from the winner (Gen 2) to the losers (Gen 1 and the Load), all participants could be made

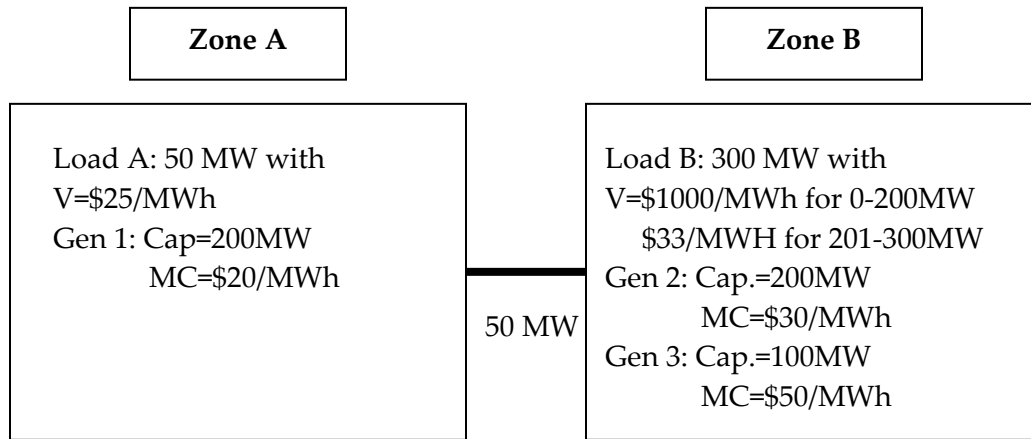
<sup>4</sup> Note that we are assuming that there is no SGOL program. With an SGOL program and LMP, Gen 1 could still offer at marginal cost and be provided an SGOL “top-up” payment to cover its start-up cost. Given that the SGOL program does not optimize over start-up cost but instead selects units based on their offer and then pays the “top-up” payment, LMP with SGOL would also lead to the inefficient outcome identified under the uniform pricing regime.

better off or at least no worse off under a LMP. A transfer of \$200 to Gen 1 and \$3500 to the load from Gen 2 would accomplish this leaving no participant worse off but Gen 2 strictly better off by \$300.

**Example 2: Inefficient consumption**

In this example, we modify our assumptions of the load and generation mix of the previous example. The load and generation mix are described in Figure 2 below.

**Figure 2: Two Zone Model with Non-Dispatchable, Price Responsive Load in Zone A**



*Load*

There are now two loads. A price responsive non- dispatchable load, Load A is located in Zone A and the dispatchable Load B located in Zone B. Load A is willing to consume 50 MW of electricity if the HOEP is less than or equal to \$25/MWh. Load B is willing to consume 300 MW if HOEP is less than or equal to \$33/MWh but only 200 MW if HOEP is greater than \$33/MWh but less than \$1000/MWh.

*Generator*

No change in assumptions from the previous example except now we assume that Gen 1 has zero start-up costs.

### **Allocative Efficient Outcome**

Once again, allocative efficiency is about maximizing the net benefit attained from the use of available resources. It involves comparing the cost of producing an extra unit – marginal cost - with the benefit gained from its consumption – marginal benefit and increasing the amount produced until the marginal benefit is equal to the marginal cost.

In this example, to understand what the efficient allocation is, we can allocate the lowest cost generation to the highest valued consumption first (subject to transmission constraints), and do so until there are no net benefits that can be achieved through further allocation. The highest valued consumption is from Load B who values the first 200 MW of consumption at \$1000/MWh. The lowest cost supply would first come from Gen 1 in Zone B. But Gen 1 can provide only 50 MW given the transmission constraint. The net benefit from the production of this 50 MW is  $(\$1000 - \$20) \times 50\text{MW} = \$49,000$ . The next lowest-cost 150 MW available to supply Load B would come from Gen 2 at \$30. The net benefit of this 150MW supplied is  $(\$1000 - \$30) \times 150\text{MW} = \$145,500$ . Load B then values the next 100 MW of consumption at \$33/MWh. There is a net benefit from Gen 2 producing the remaining 50 MW of its capacity to supply load B. The net benefit from this supply is  $(\$33 - \$30) \times 50\text{MW} = \$150$ . Given that the cost of Gen 3 is \$50, there are no more gains from trade that can be realized from producing to supply Load B.

Now, Load A values 50 MW of consumption at \$25/MWh. Given the transmission constraint, Gen 1 has 150 MW of idle capacity at a cost of \$20. There is a positive net benefit that is realized from having Gen 1 produce an additional 50 MW to supply Load A. The net benefit from this production is  $(\$25 - \$20) \times 50\text{MW} = \$250$ . Summing all of the net benefits gained from this allocation leads to a total net benefit equal to \$194,900. No other allocation of resources can be found that would provide a higher net benefit.

Again, with this as the efficiency benchmark, let's now look at what would happen under both uniform and locational pricing regimes.

### **Uniform Pricing Regime Results**

Under a uniform pricing regime, the HOEP is determined by ignoring the 50 MW transmission constraints between the two zones. Ignoring the transmission constraint, the unconstrained schedule would stack up offers so as to supply the load with the highest valuation of consumption in the province first. The 300 MW of demand of Load B would be supplied with 200 MW from Gen 1 and 100 MW of Gen 2. Gen 3 would not be scheduled in the unconstrained sequence.

With the HOEP at \$30, Load A would not consume since the price is higher than the value that it places on consumption. There is a presumption that Load A would anticipate that

HOEP would be \$30 and would be capable of responding to the price signal and shut down its production. It also assumes that the IESO would forecast the provincial load accurately.

The constrained schedule would recognize the transmission constraint and would schedule Gen 1 for only 50. As with the previous example, Gen 1 would be constrained-off by 150 MW. Similarly, Gen 2 is scheduled for 200 MW (constrained on for 100 MW). Load B is scheduled to consume 250 MW. Given that the marginal cost of the 251<sup>st</sup> MW is the \$50 offer from Gen 3, it would not be economic for Load B to consume the 251<sup>st</sup> MW in the constrained schedule. Load B would be constrained-off for 50 MW (dispatched to reduce consumption). Gen 3 does not produce in the constrained sequence. The shadow prices are \$20 in Zone A and \$33 in Zone B with the Zone B shadow price being set by the Load B bid price.

The welfare of each participant under the uniform pricing regime is provided in Table 3 below.

**Table 3: Welfare Cost of Production under Uniform Pricing Regime with Two Loads**

<b>Participant</b>	<b>Cost of Production</b>	<b>Welfare</b>
<b>Gen 1</b>	MC x Output = \$20 x 50 MW = \$1,000	Energy revenue plus CMSC less production cost = \$30 x 50 MW + (\$30 - \$20) x 150 MW - \$1,000 = \$2,000
<b>Gen 2</b>	MC x Output = \$30 x 200 MW = \$6,000	Energy revenue plus CMSC less production cost = \$30 x 200 MW + (\$30 - \$30) x 100 MW - \$6,000 = \$0
<b>Gen 3</b>	MC x Output = \$0 MW = \$0	Energy Revenue plus CMSC less production cost = \$0 = \$0
<b>Load A</b>		Value of consumption less energy cost less uplift = \$0
<b>Load B</b>		Value of consumption less energy cost plus CMSC less uplift \$1000 x 200 MW + \$33 x 50 MW - \$30 x 250 MW + (\$33 - \$30) x 50 MW - (\$30 - \$20) x 150 MW - (\$33 - \$30) x 50 MW = \$192,650
<b>Total</b>	= \$7,000	= \$194,650

The uniform pricing regime leads to an inefficient level of consumption in Zone A. The inefficiency is valued as the loss of the net benefit from this consumption which is \$250. Note that in our simplified example Load B as the only consumer of electricity pays the full market uplift including the dollars that they receive in constrained off payments as a dispatchable load.

## Locational Marginal Pricing Regime Results

A LMPR would induce the efficient outcome in this example. Under LMPR, the locational price in Zone A would be \$20. At this price Load A would consume 50 MW. Gen 1 would produce 100 MW; the first 50 MW would be sent to Zone B for Load B (the higher valuation consumer) and the next 50 MW would be used to supply Load A in Zone A. Gen 2 would produce 200 MW and Load B would consume 250MW. Because the marginal cost of another unit of supply sets the LMPR, and it must be at or below the marginal benefit of another unit of demand which is \$33/MWh. Gen 3 would not produce.

Note, in the LMP world there is a congestion rent that is collected as the difference between the prices in the two zones times the flow limit of the transmission line. The value of the congestion rent is  $(\$33-\$20) \times 50\text{MW} = \$650$ . For simplicity of this example, assume that Gen 1 was grandfathered the ownership of the transmission rights on this line and hence a right to the congestion rents.

Table 4 outlines the welfare of each participant under a LMPR.

**Table 4: Welfare Cost of Production under LMPR with Two Loads**

<b>Participant</b>	<b>Cost of Production</b>	<b>Welfare</b>
<b>Gen 1</b>	MC x Output = \$20x100MW  =\$2,000	Energy revenue less production cost plus congestion rents = \$20x100MW - \$2000 + \$650  =\$650
<b>Gen 2</b>	MC x Output = \$30x200MW  =\$6,000	Energy revenue less production cost = \$33x200MW - \$6,000  =\$600
<b>Gen 3</b>	MC x Output = \$0  =\$0	Energy Revenue less production cost   =\$0
<b>Load A</b>		Value of consumption less energy cost = \$25*50 MW - \$20*50 MW  =\$250
<b>Load B</b>		Value of consumption less energy cost = \$1000x200MW + \$33x50MW - \$33x250MW  =\$193,400
<b>Total</b>	  =\$8,000	  =\$194,900

As Table outlines, a LMPR induces the efficient outcome. An increase of production costs of \$1000 induces an increase in overall welfare in the province of \$250. The value placed on

consumption from the production of the additional 50 MW from Gen 1 by Load A is \$1,250 ( $\$25 \times 50 \text{ MW}$ ), which is higher than the production cost.

As was the case with the first example, moving from a uniform pricing regime to a LMP creates winners and losers. In this example, only Gen 1 is the loser. All other participants are either better off or no worse off.

## **Examples of Dynamic Inefficiencies**

### *Example 3: Incentives for Capacity Investment*

For this example, we will assume the same market structure that existed in example 1 above. However, we now assume that there is a new technology that is available in the industry that would allow any generation unit to increase its capacity by as much as 5 MW. The cost to invest in the technology is \$5 per MW of additional capacity. If the investment is made, the additional 5 MWs can be produced at the same marginal cost of the previous units of output.

#### **Allocative Efficient Outcome**

The efficient outcome would be for Gen 2 to invest in the technology permitting it to produce an additional 5 MW. If Gen 2 invests in the technology, it can provide an additional 5 MW to the load at a marginal cost of \$30/MWh. In this case, Gen 3 would reduce its production by 5MW. The efficiency gain is the difference between the marginal cost between the two generators times the amount of increased capacity –  $(\$50 - \$30) \times 5 \text{ MW} = \$100$  which is more than the cost of the resources required to make the investment –  $\$5 \times 5 \text{ MW} = \$25$ . The net gain from the investment would therefore be \$75 which is the difference between the production costs saved less the cost of the investment.

It would not be efficient for Gen 1 to make the investment since, due to the transmission constraint, the additional capacity could not be utilized – no net benefit from the additional capacity. Similarly, Gen 3, the higher cost generator, already has idle capacity and hence there would be no net benefit from capacity expansion.

#### **Uniform Pricing Regime Results**

What is the private incentive for each of the generators to invest in the new technology under a uniform pricing system? Under uniform pricing, if Gen 1 invests in the technology to expand its capacity by 5 MW, it will increase its unconstrained sequence by 5 MW and receive an additional constrained-off payment equal to  $(\$30 - \$20) \times 5 \text{ MW} = \$50$  which is larger than the cost of the investment. Gen 1 will have the incentive to invest, even though the extra capacity will remain idle.

Gen 2 will not have an incentive to invest in the additional 5 MW capacity. If Gen 2 invested, it would be constrained on for 5 MW with Gen 3 correspondingly backed down by 5 MW. But given that its offer sets the HOEP, while it is eligible for a constrained on payment, the amount is zero. Gen 3 would have no incentive to invest in the technology as it already had idle capacity that is not receiving revenue.

**Table 5: Welfare Cost of Production under Uniform Pricing Regime – Gen 1 Investing in Technology to Expand Capacity**

<b>Participant</b>	<b>Cost of Production</b>	<b>Welfare</b>
<b>Gen 1</b>	MC x Output plus SC $=\$20 \times 50\text{MW} + \$1,800$ $=\$2,800$	Energy revenue plus CMSC less production cost less investment $=\$30 \times 50\text{MW} + (\$30 - \$20) \times 155\text{MW} - \$2,800 - \$25$ $=\$225$
<b>Gen 2</b>	MC x Output plus SC $=\$30 \times 200\text{MW} + \$0$ $=\$6,000$	Energy revenue plus CMSC less production cost $=\$30 \times 200\text{MW} + (\$30 - \$30) \times 105\text{MW} - \$6000$ $=\$0$
<b>Gen 3</b>	MC x Output plus SC $=\$50 \times 50\text{MW} + \$0$ $=\$2,500$	Energy Revenue plus CMSC less production cost $=\$30 \times 50\text{MW} + (\$50 - \$30) \times 50\text{MW} - \$2,500$ $=\$0$
<b>Load</b>		Value of consumption less energy cost less uplift $\$1000 \times 300\text{MW} - \$30 \times 300\text{MW} - (\$10 \times 155\text{MW} + \$20 \times 50\text{MW})$ $=\$288,450$
<b>Total</b>	$=\$11,300$	$=\$288,675$

Compared with the welfare result in Table 1 (\$288,700), this investment creates an inefficiency of \$25 which is equal to the \$25, the cost of the investment.

**Locational Marginal Pricing Regime Results**

The LMP regime provides the private incentives for efficient investment. In an LMP world both Gen 1 (due to transmission constraints) and Gen 3 would not have the incentive to invest since they already have idle capacity that does not receive revenue. The incremental capacity would remain idle and both generators would not be able to recover the cost of the investment.

Gen 2 would have an incentive to invest in the technology to expand its capacity by 5 MW. Gen 2 would be able to sell the additional 5 MW at the Zone B of \$50. It would earn net

revenue of  $(\$50-\$30) \times 5 \text{ MWh} = \$100 \text{ MWh}$  which exceeds the cost of the investment. The efficiency gained would be again be \$75 computed as the difference between the production cost saved from having 5 MW more of the \$30 generation and backing down 5 MW of the \$50 generation, less the investment cost ( $\$5\text{MW} \times 50\text{MWh}$ )- $(\$20 \times 5 \text{ MWh}) -\$25$ ).

**Table 6: Welfare and Cost of Production under Locational Regional Pricing - Gen 2 Investing in Technology to Expand Capacity**

<b>Participant</b>	<b>Cost of Production</b>	<b>Welfare</b>
<b>Gen 1</b>	MC x Output less SC =\$0	Energy revenue less production cost =\$0
<b>Gen 2</b>	MC x Output less SC =\$30x205MW-\$0 =\$6,150	Energy revenue less production cost =\$50x205MW -\$6,150 - \$25 =\$4075
<b>Gen 3</b>	MC x Output less SC =\$50x95MW-\$0 =\$4,750	Energy Revenue less production cost =\$50x95MW-\$4,750 =\$0
<b>Load</b>		Value of consumption less energy cost less uplift \$1000x300MW - \$50x300MW =\$285,000
<b>Total</b>	=\$10,900	=\$289,075