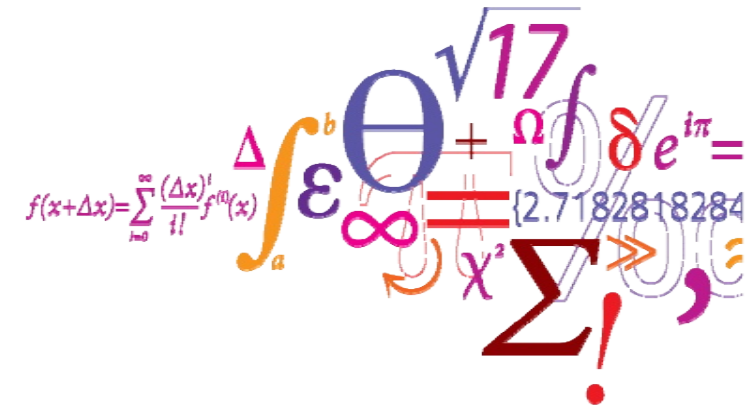


31761 – Renewables in Electricity Markets

Lecture 9: Electricity Market Properties under Uniform Pricing and Strategic Participants

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Email: liyha@dtu.dk

March, 2022



Technical University of Denmark
Department of Wind and Energy Systems

Learning Objectives

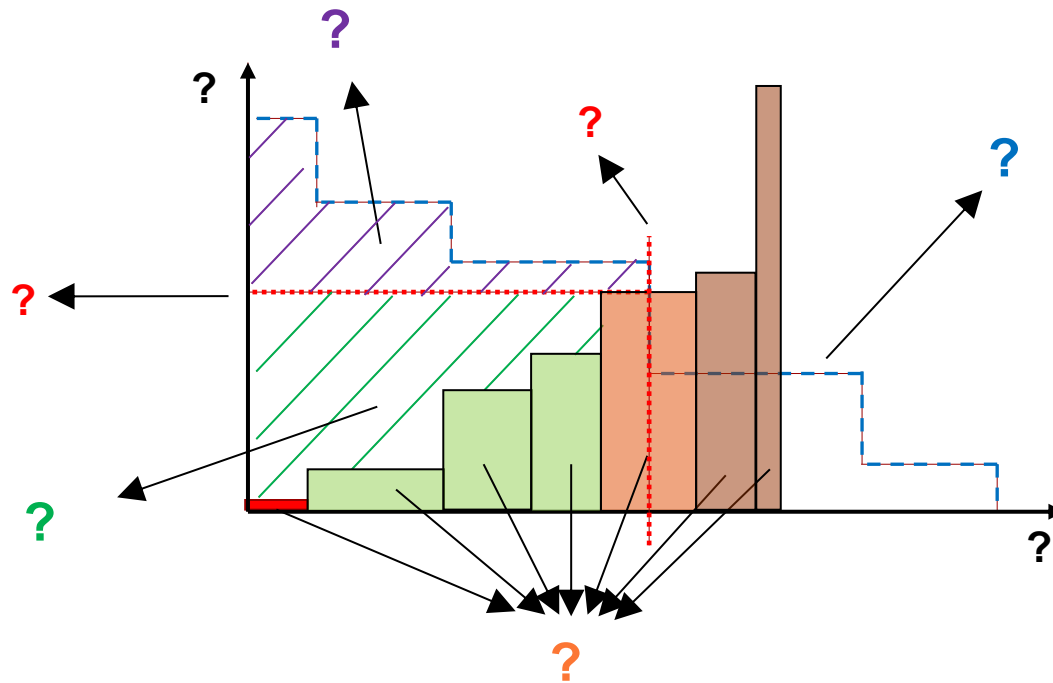
In today's lecture, we will be discussing the **market properties** under **uniform pricing**, and potential price-maker strategies.

After this lecture, you should be able to

1. Explain the differences between a **price-maker** and a **price-taker**;
2. Name and provide the definitions of the four desirable **market properties**;
3. Name two types of **strategic actions** in the energy market from the producers' perspective, and explain the impact these actions have on the market clearing **price**, clearing **quantity**, the **payoffs** of all the market participants, and the **social welfare**;
4. Formulate the market clearing under uniform pricing both in an **optimization problem** and on a **merit-order curve**, and match each parameter and variable in the optimization problem to the corresponding graphical representation in the merit-order curve.

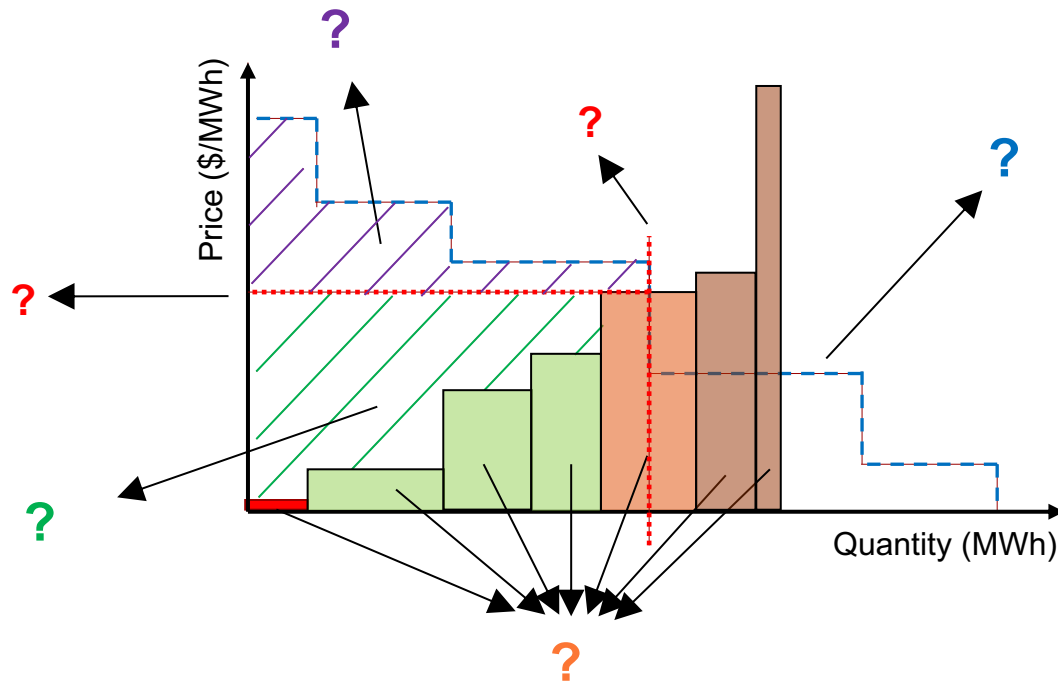
Recap

Electricity market clearing with the merit-order



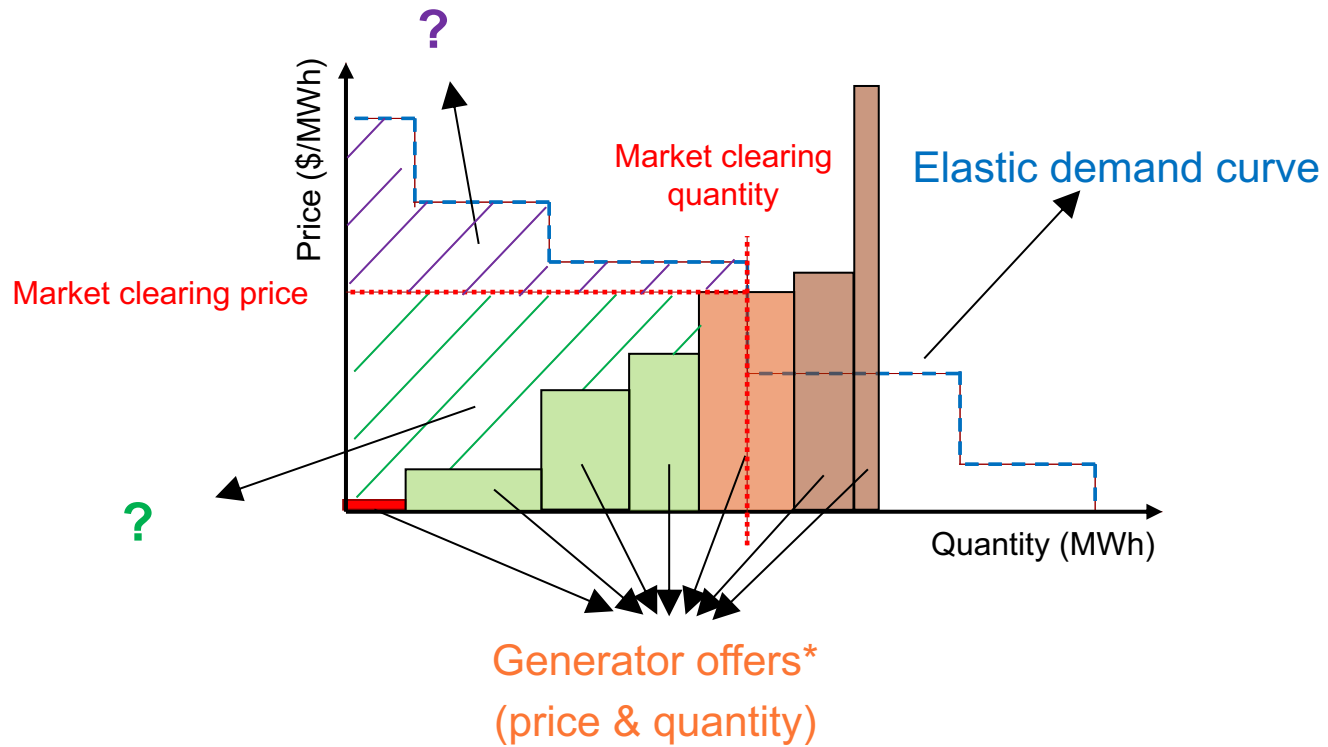
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Recap

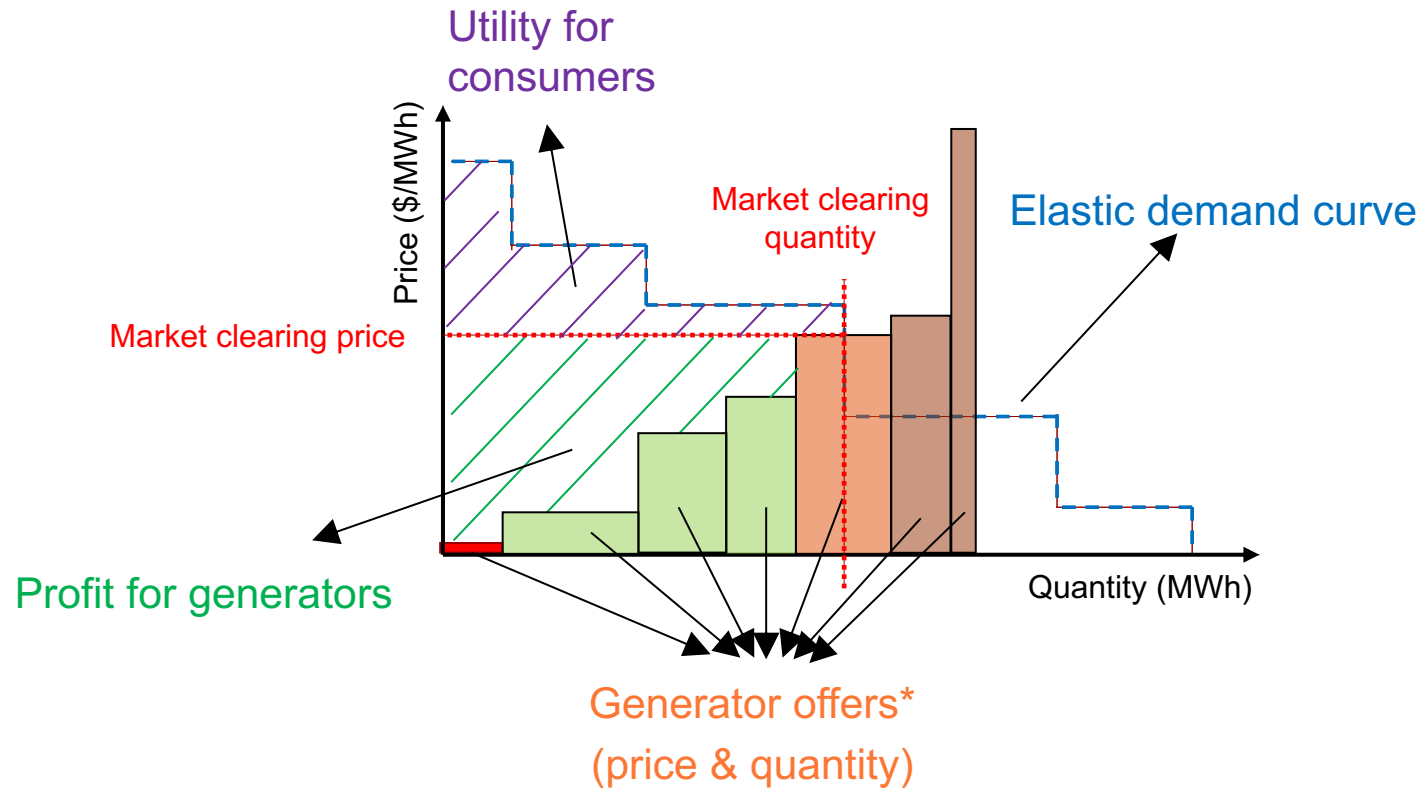
Electricity market clearing with the merit-order



*Assumption: all generators are price-takers with truthful offers:
offer prices = marginal costs and offer quantities = true capacities

Recap

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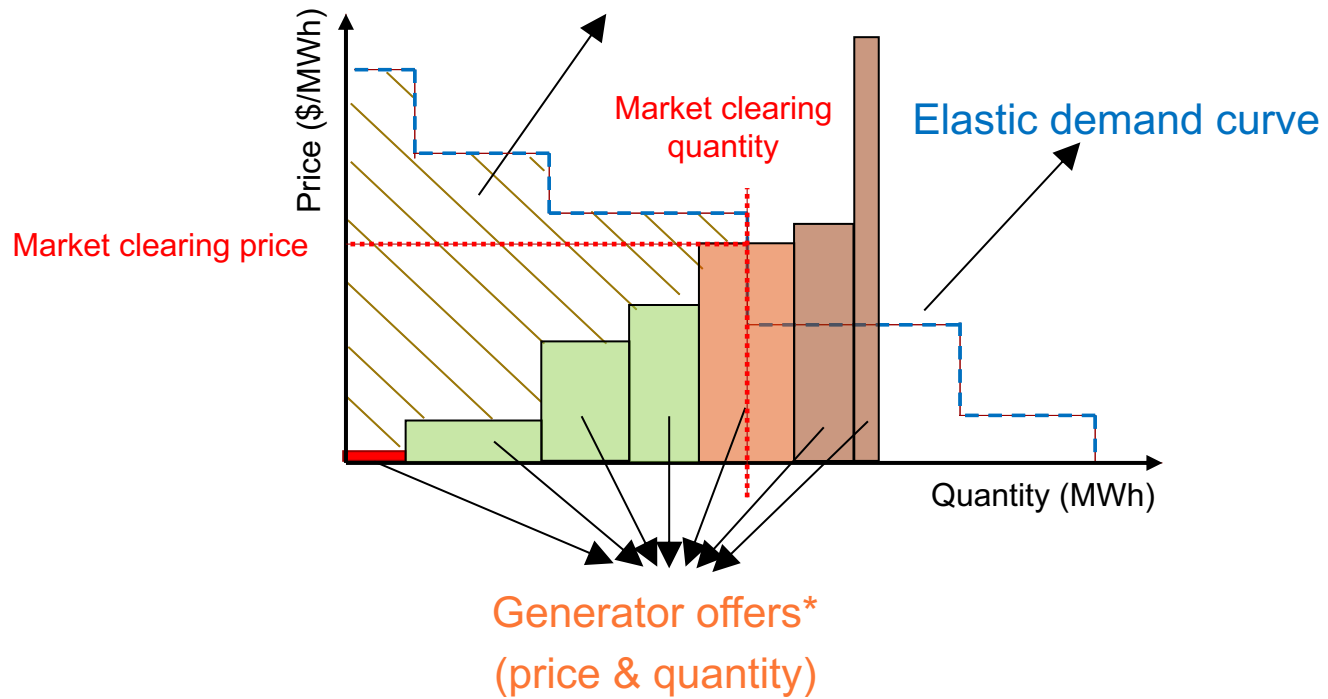


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Recap

Electricity market clearing with the merit-order

Utility for consumers + profit for generators = ?

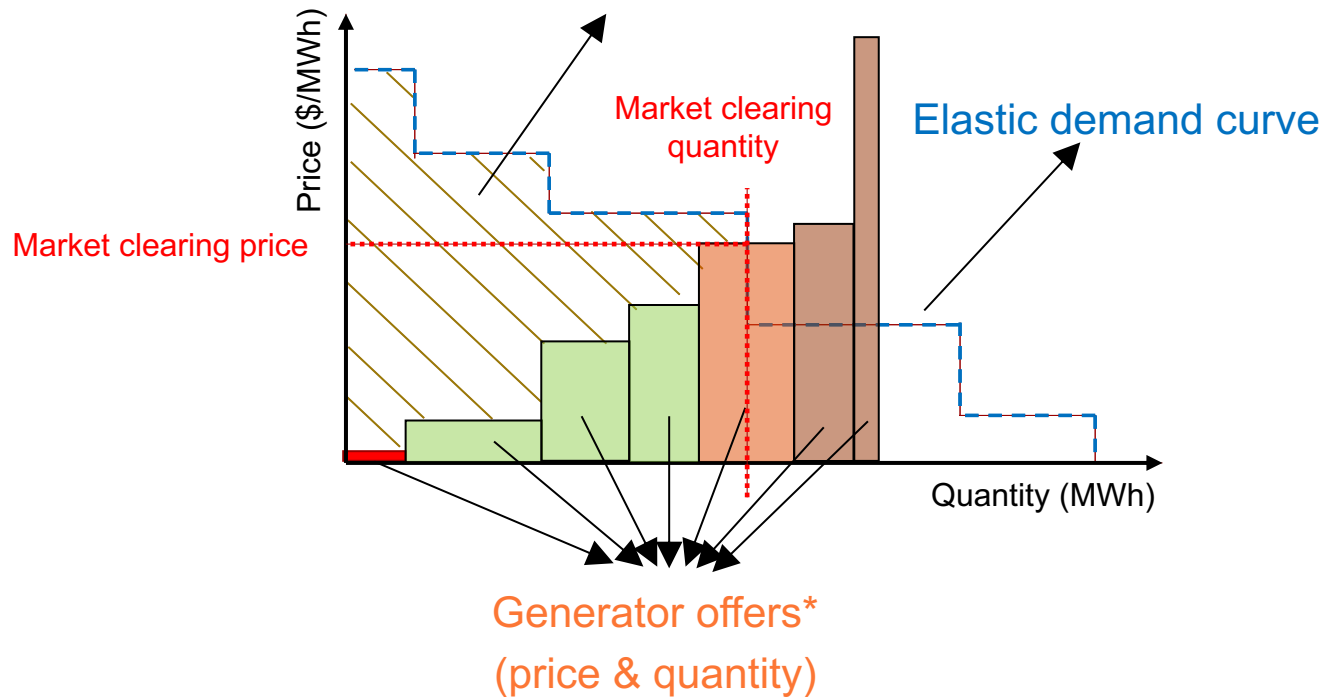


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Recap

Electricity market clearing with the merit-order

Utility for consumers + profit for generators = **Total Social Welfare (SW)**



*Assumption: all generators are price-takers with truthful offers:
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order



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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order



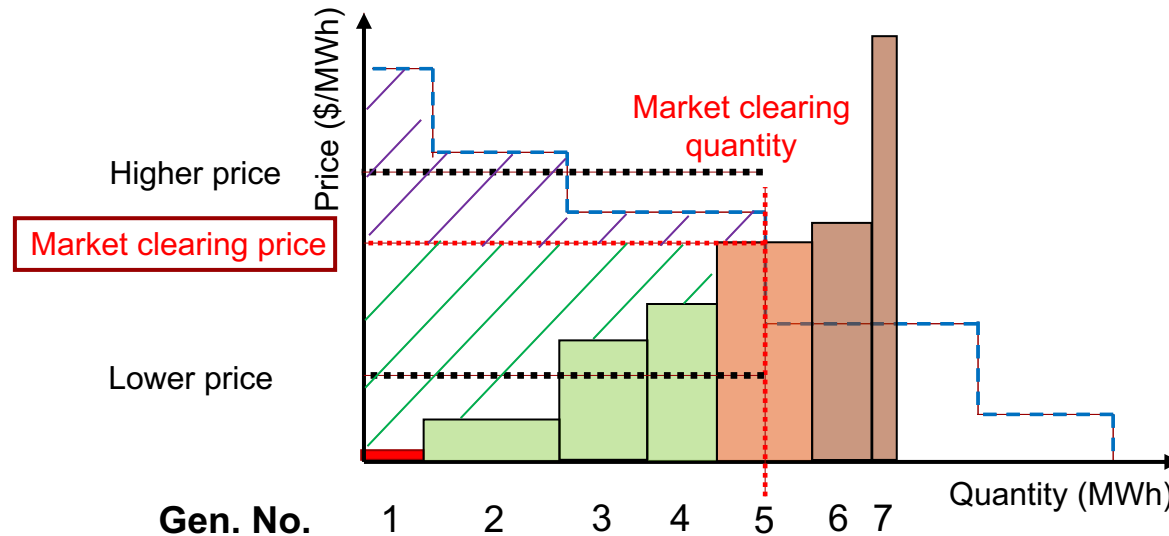
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order

Utility for consumers + profit for generators = **Total Social Welfare**



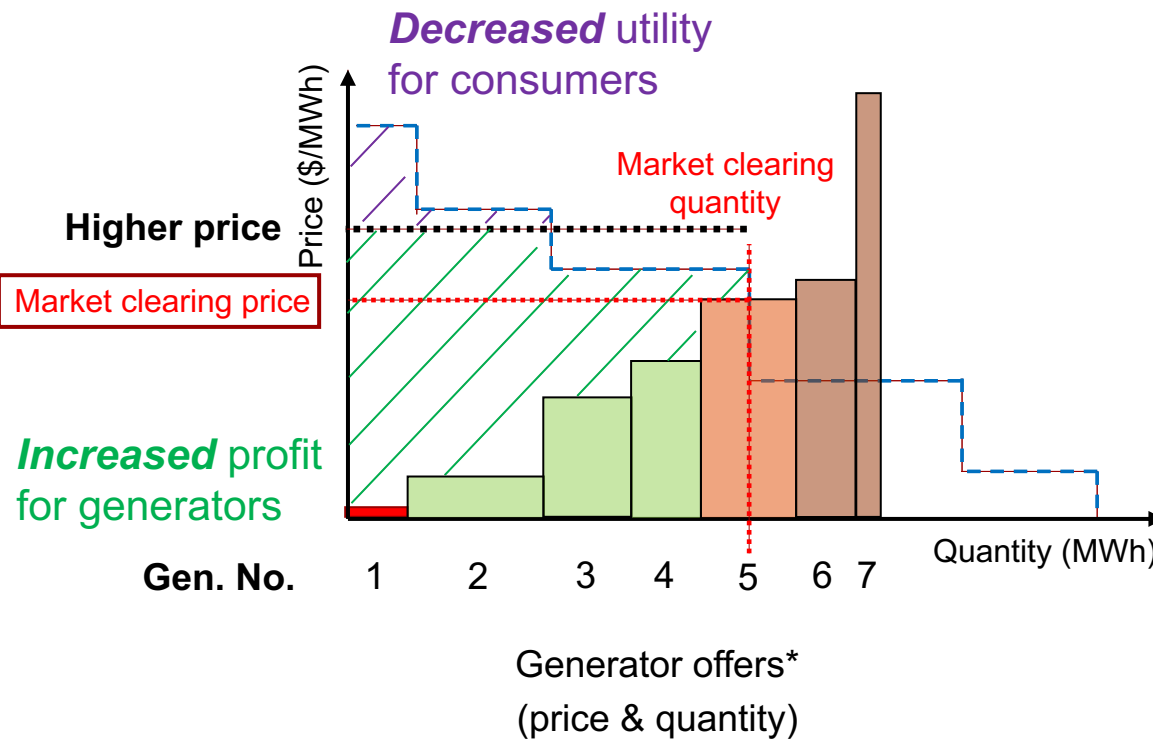
Generator offers*
(price & quantity)

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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order

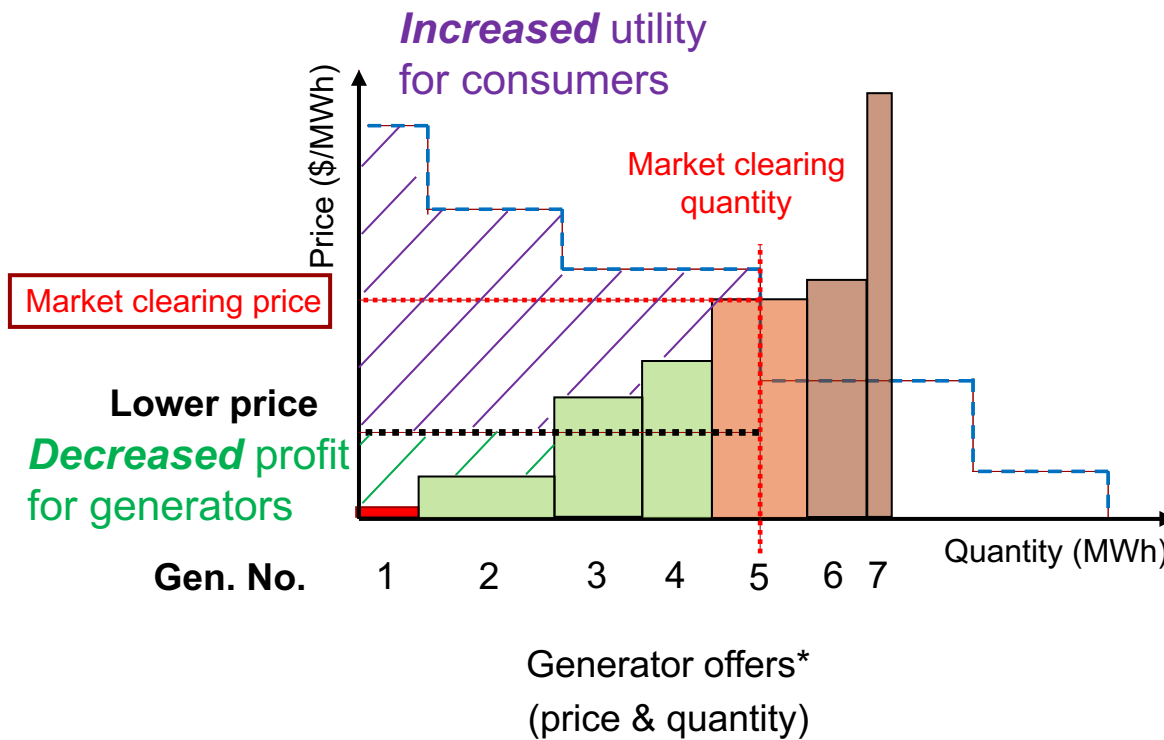


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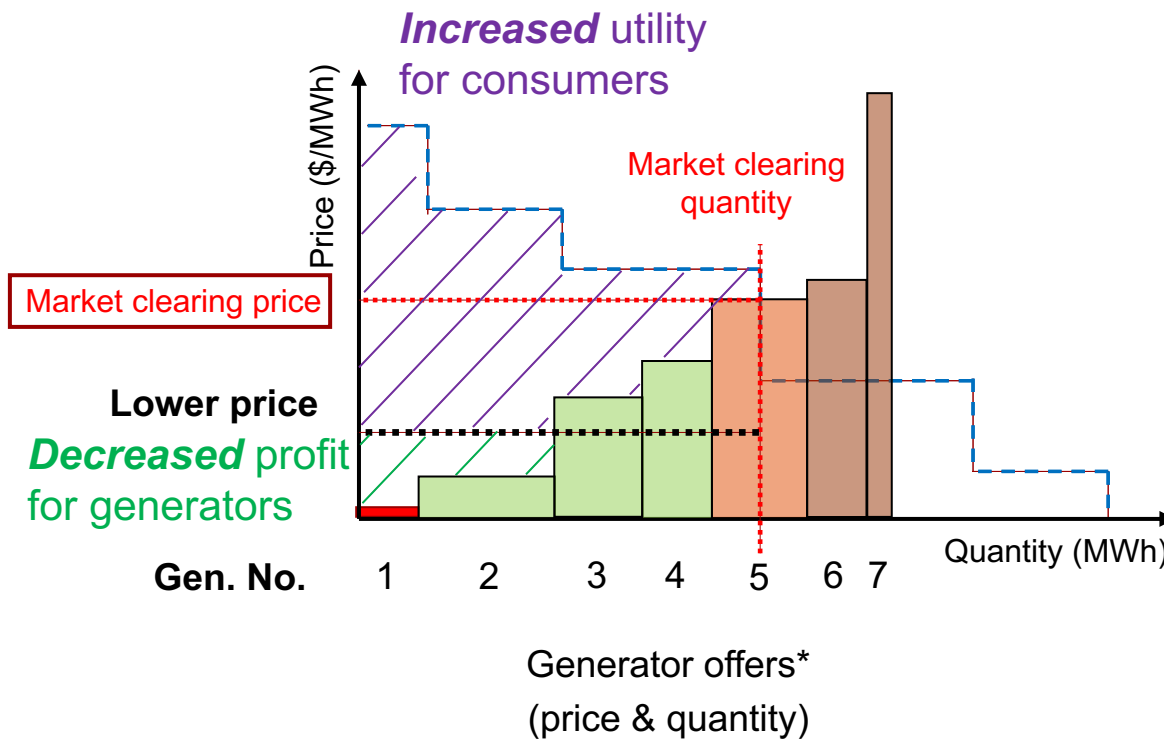


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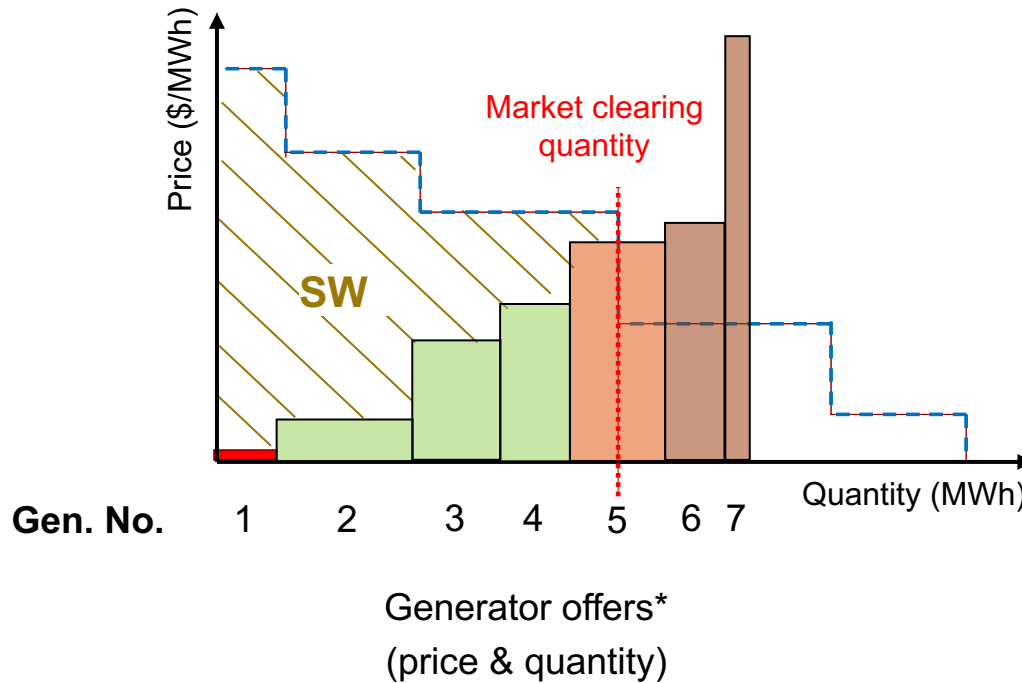
Answer:

No! The market clearing price does not impact the **total social welfare**.

It **does** impact the distribution of the social welfare between the **utility for consumers** and **profit for generators**.

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order

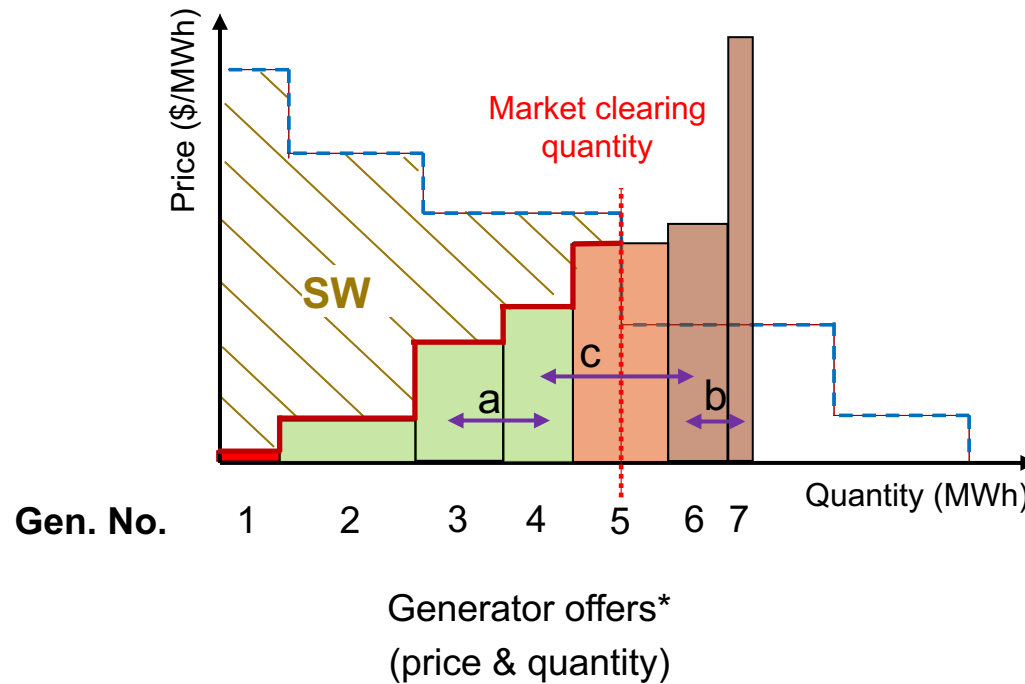


Is it possible to achieve a higher social welfare by 1) disrupting the merit-order dispatch, or 2) changing the market clearing quantity?

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Electricity Market Clearing under Uniform Pricing

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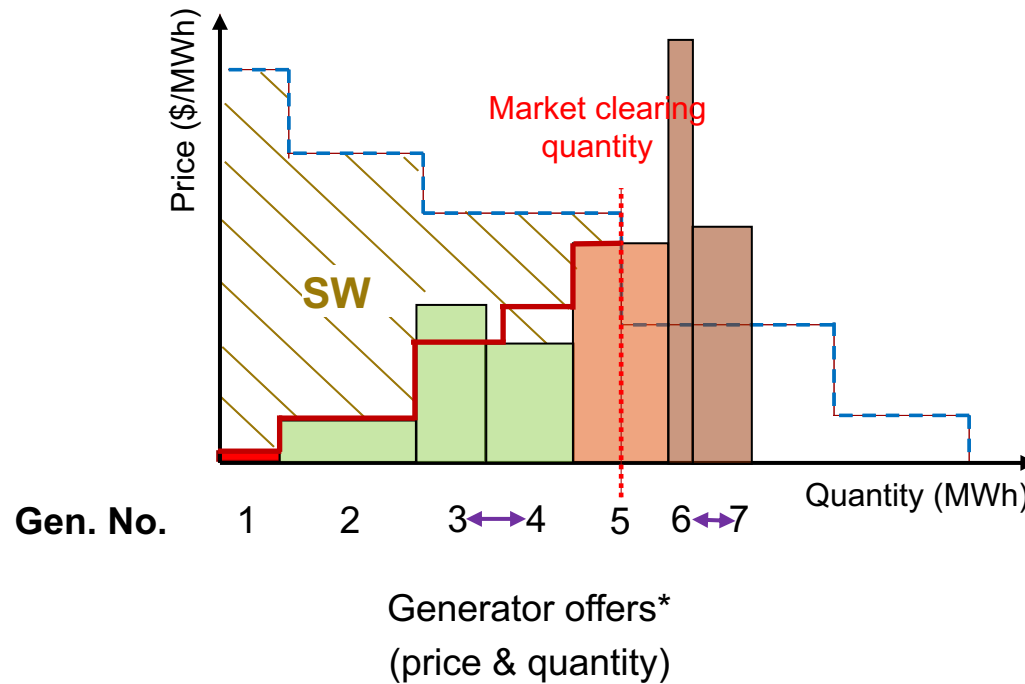
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To disrupt the merit-order, we can change the order of:

- Two dispatched generators
- Two non-dispatched generators
- One dispatched and one non-dispatched generators

Electricity Market Clearing under Uniform Pricing

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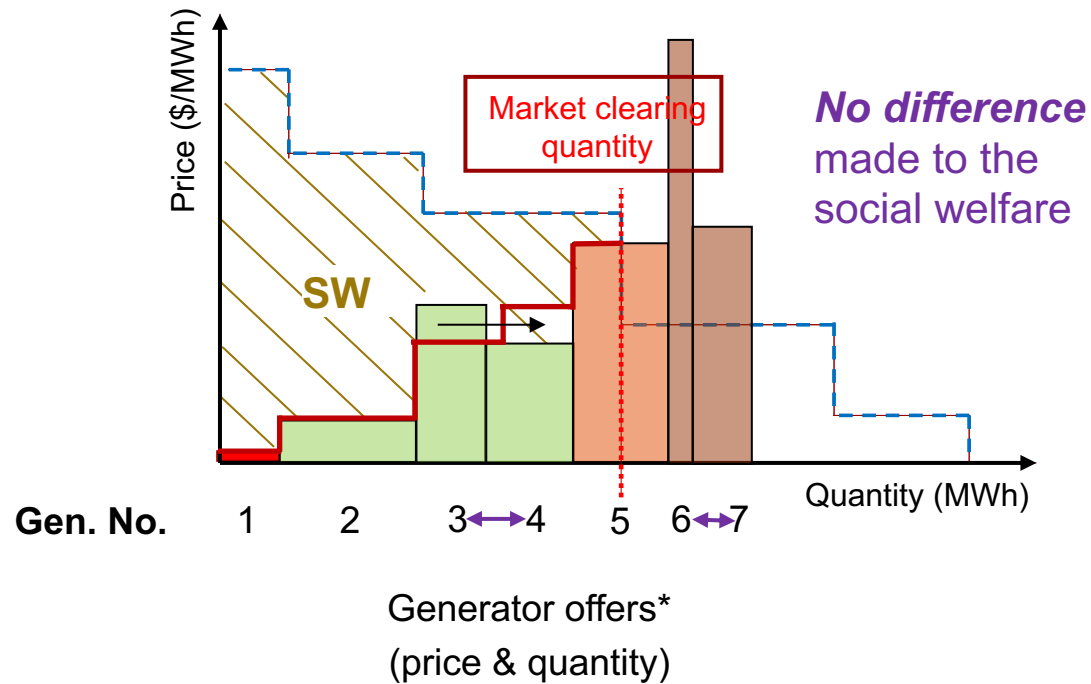
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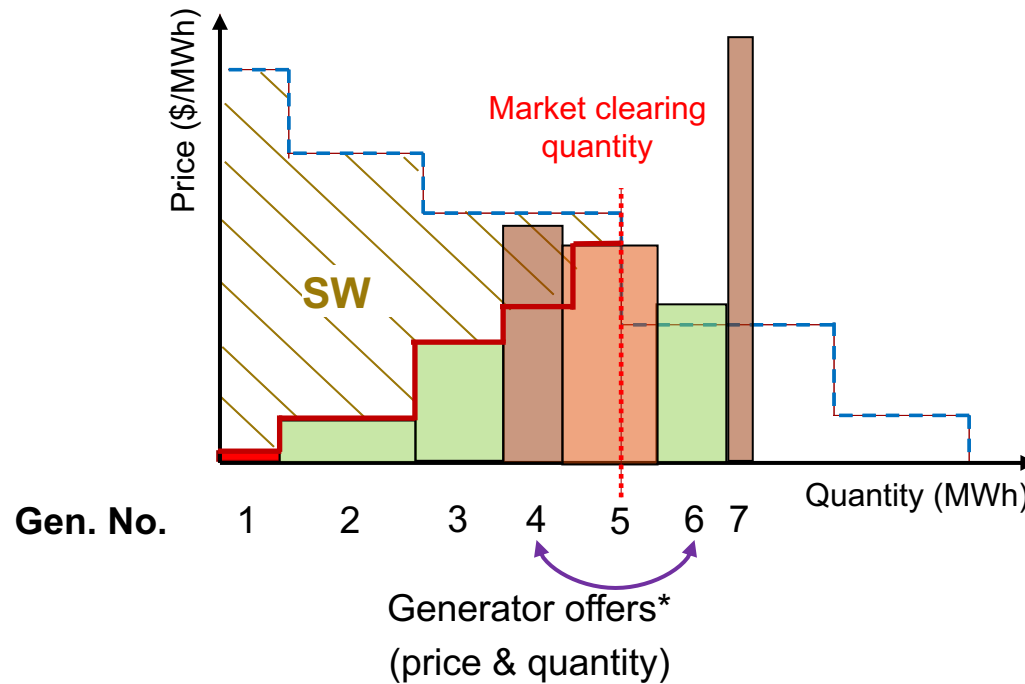
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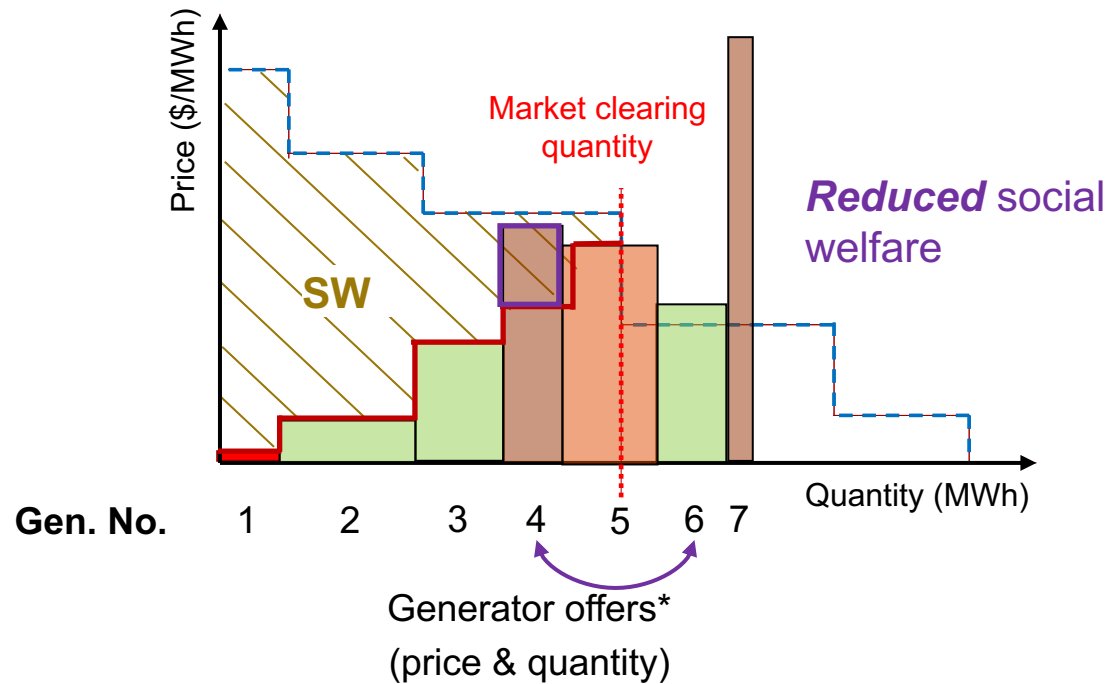
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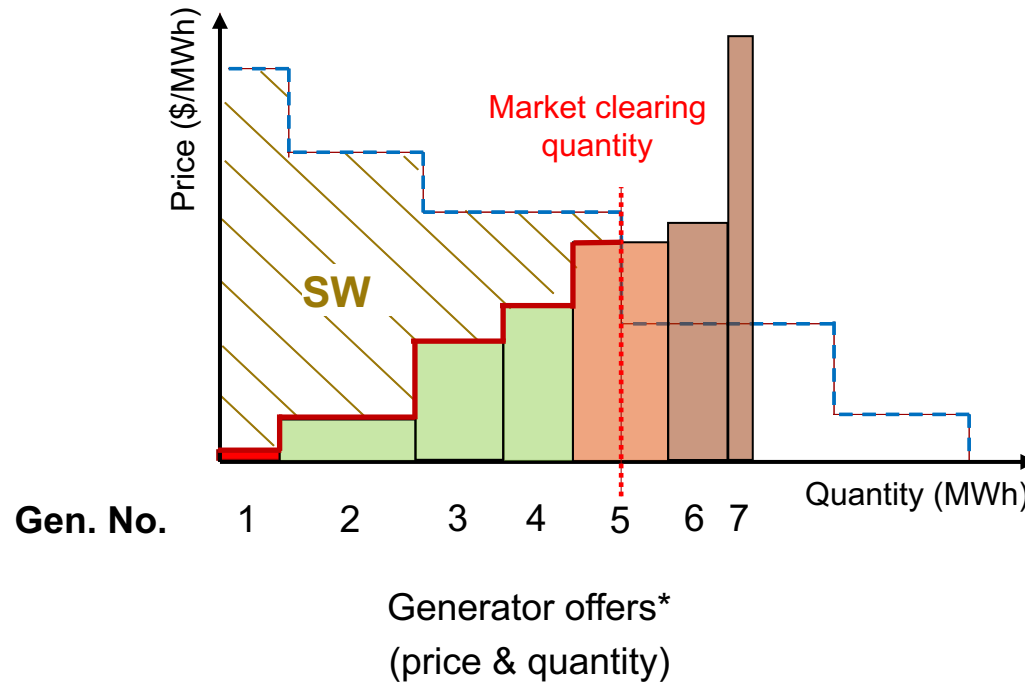
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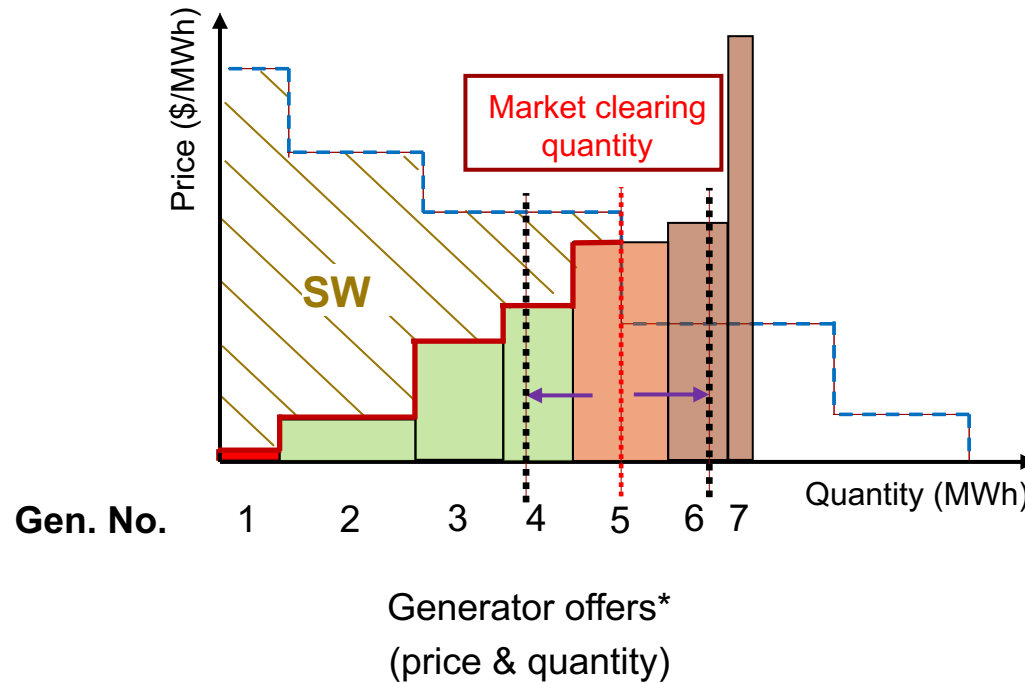
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Answer:

1) No, but it may lead to reduced SW.

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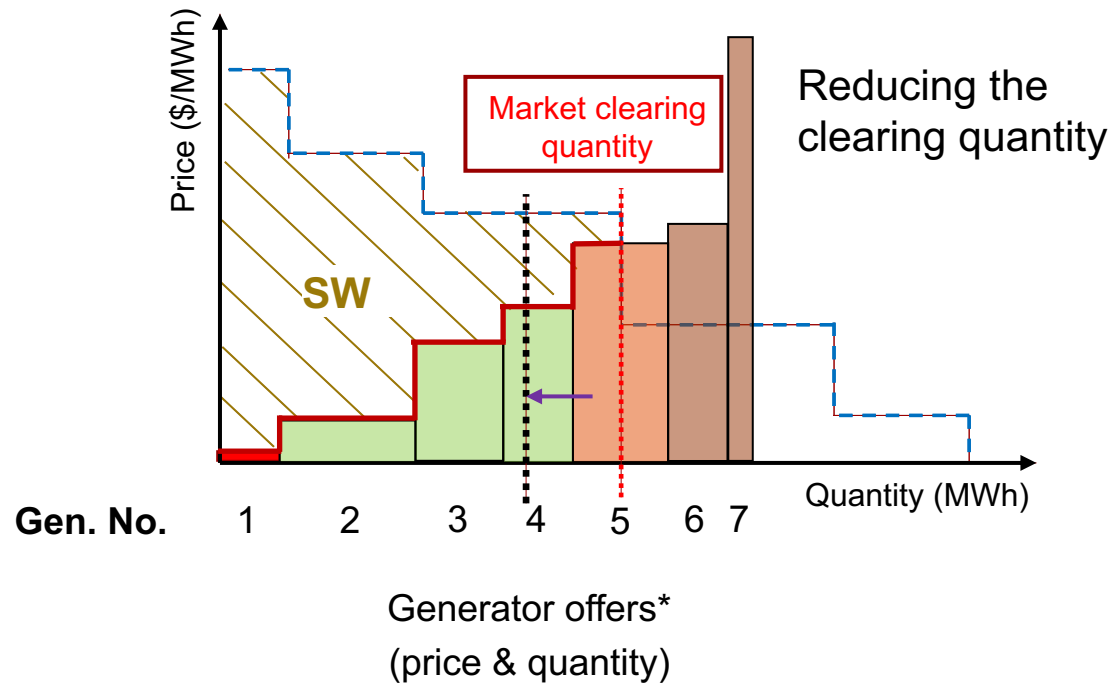
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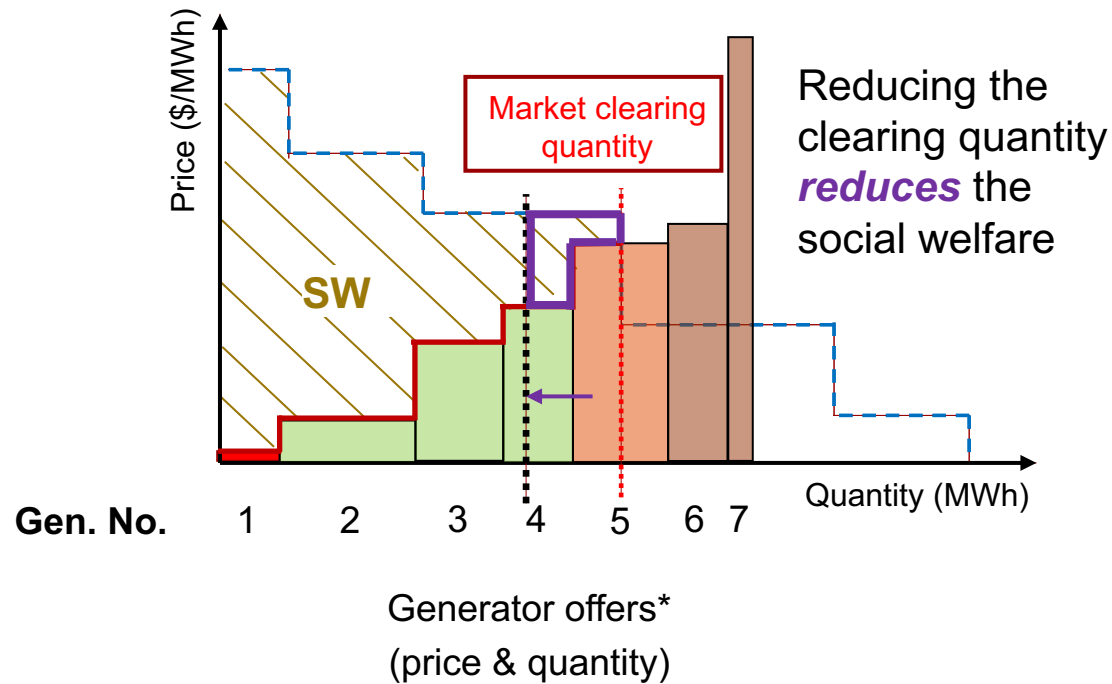
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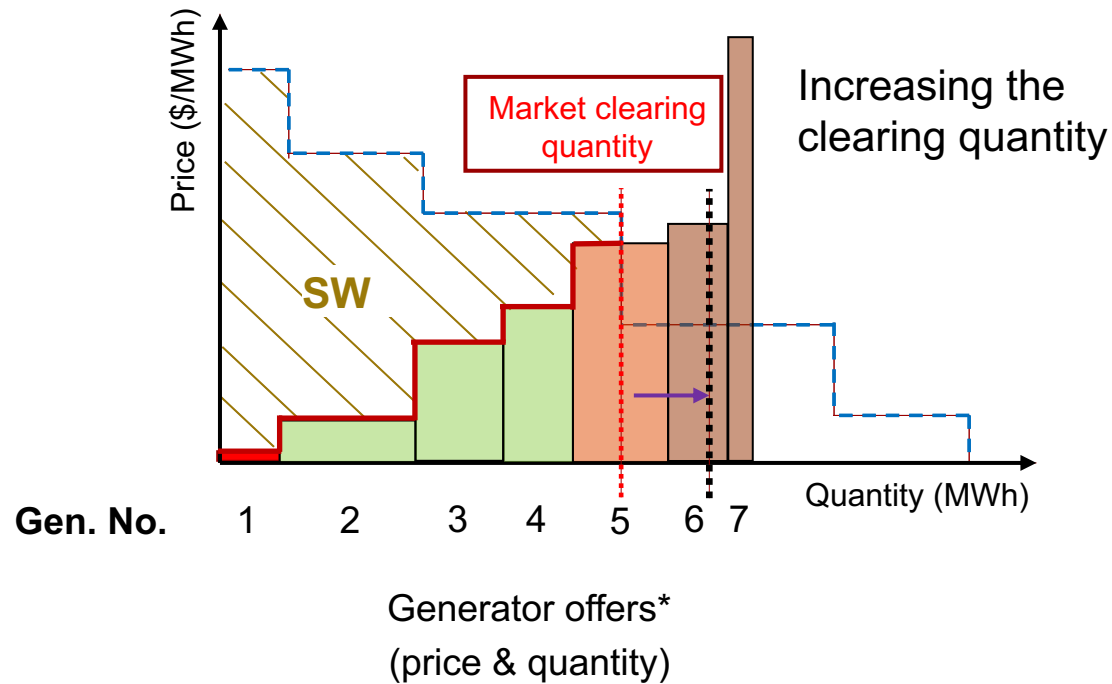
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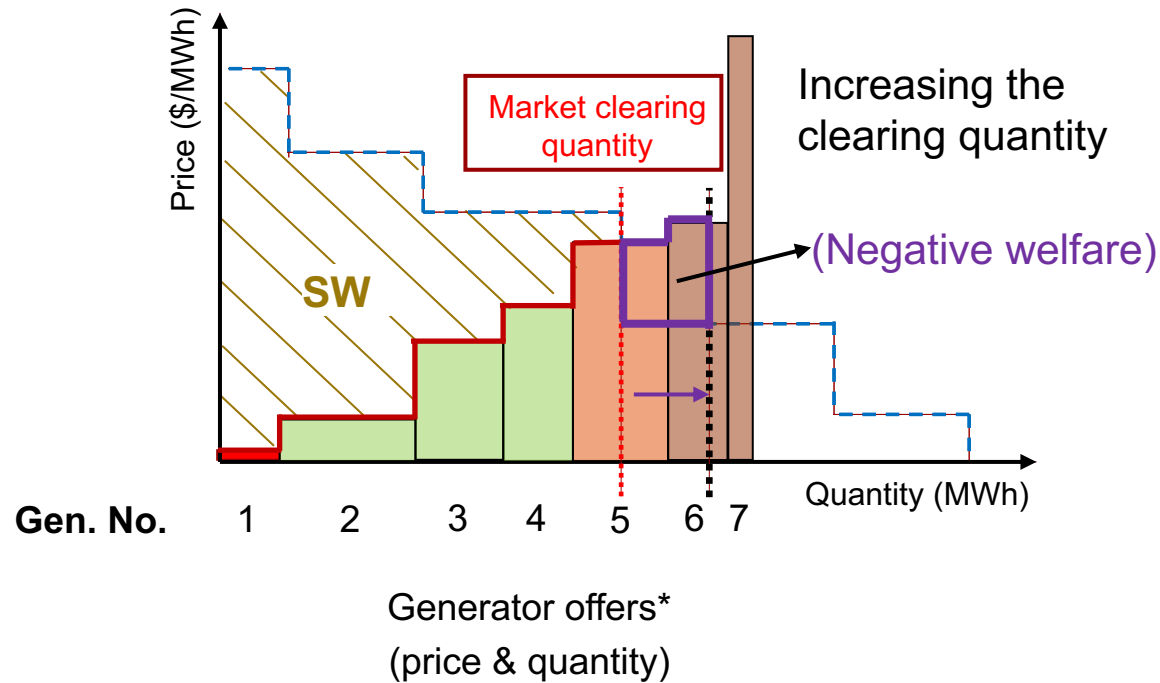
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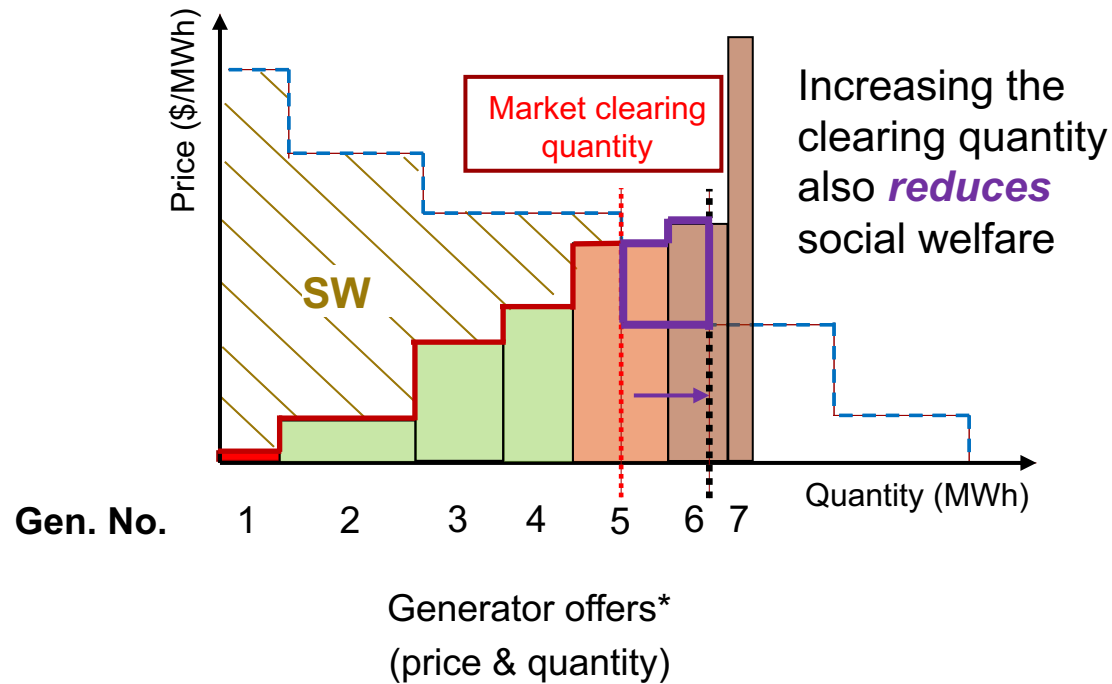
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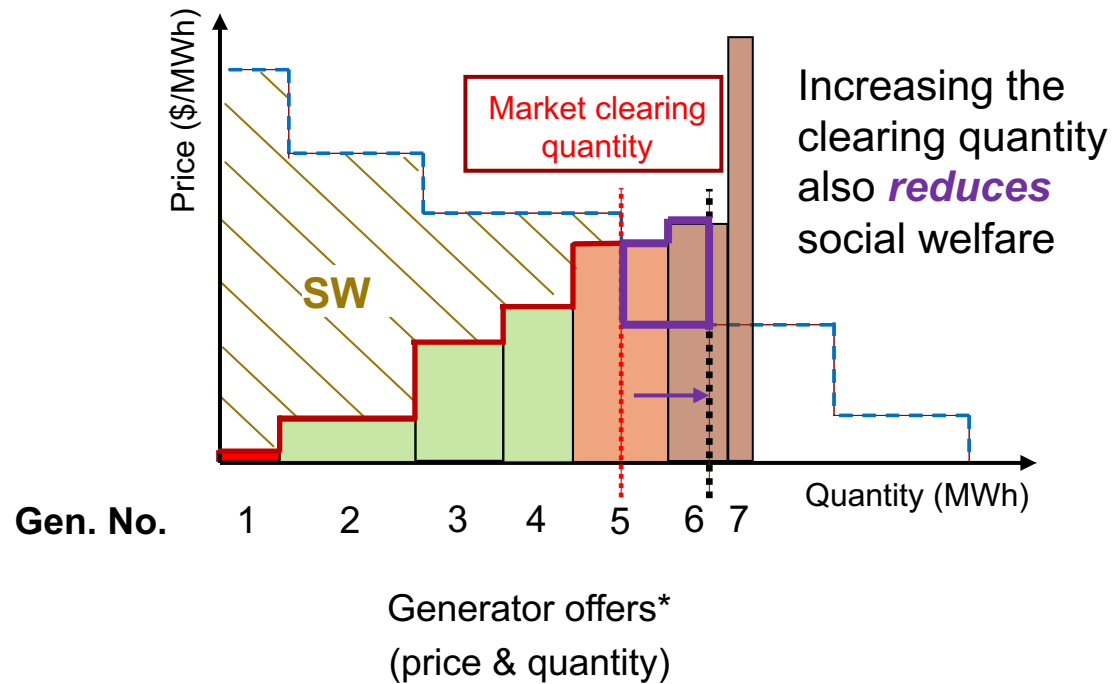
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order



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Is it possible to achieve a higher social welfare by 1) disrupting the merit-order dispatch, or 2) **changing the market clearing quantity**?

Answer:

- 1) No, but it may lead to reduced SW.
 - 2) No. It can also lead to reduced SW.
- In summary, the merit-order based market clearing **maximizes total SW**.

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



*Assumption: all generators are price-takers with truthful offers:
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



*Assumption: all generators are price-takers with truthful offers:
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Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency
2. Incentive compatibility
3. Cost recovery / individual rationality
4. Revenue adequacy (balanced budget)

Electricity Market Clearing under Uniform Pricing

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An efficient market **maximizes the social welfare**, and no one desires to unilaterally deviate from the market outcome.

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Is the electricity market under uniform pricing an **efficient** market?

Electricity Market Clearing under Uniform Pricing

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Not clear yet!

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Electricity Market Clearing under Uniform Pricing

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Every market player can maximize their objective simply by acting according to their **'true' preferences**.

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



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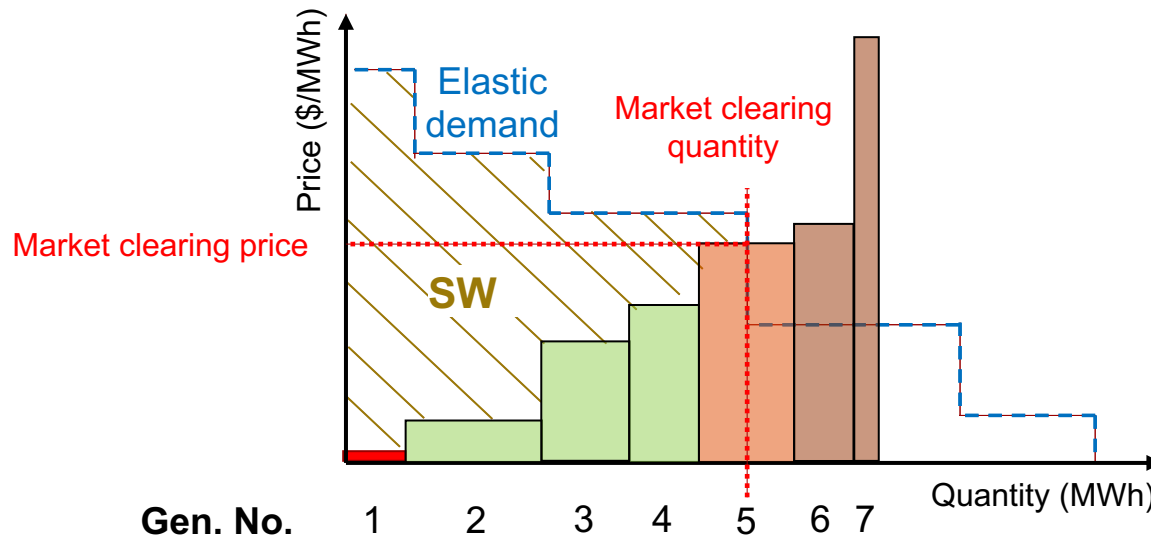
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Is the electricity market under uniform pricing **incentive compatible**?

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



Generator offers*
(price & quantity)

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Electricity Market Clearing under Uniform Pricing

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Every market player achieves a **non-negative profit/utility**.

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



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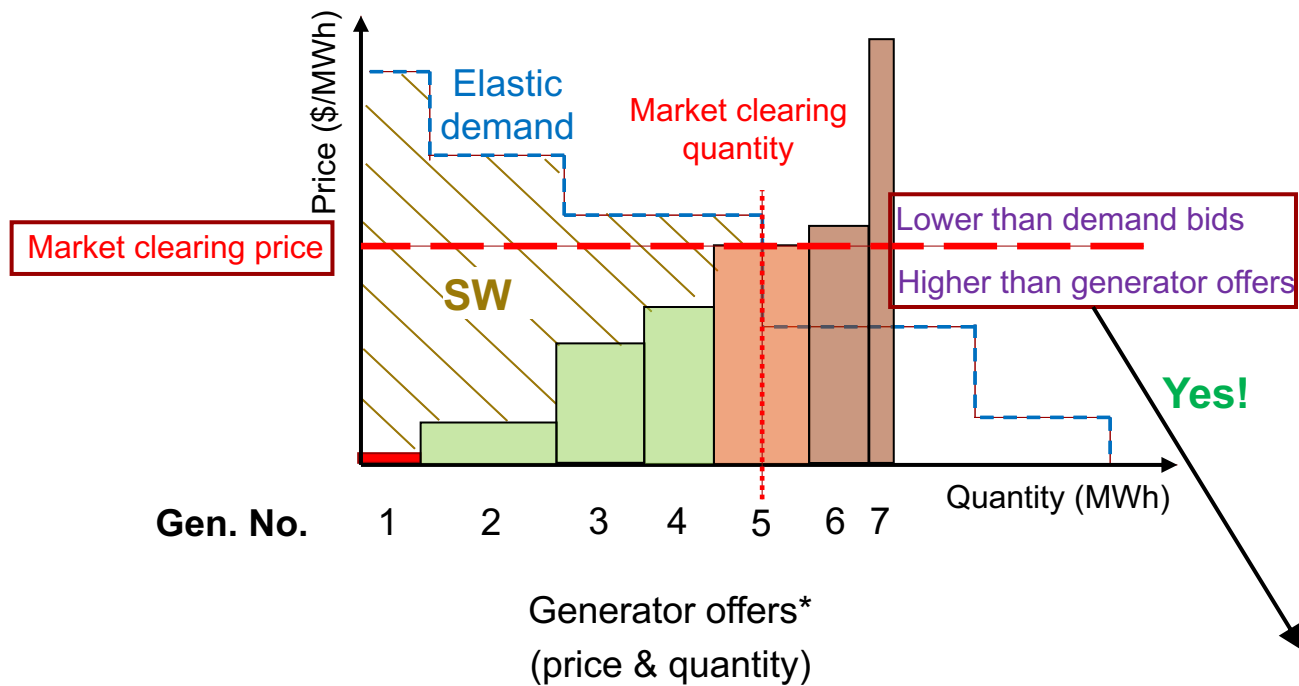
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Every market player achieves a **non-negative profit/utility**.

Is the electricity market under uniform pricing **individual rational**?

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency (?)
2. Incentive compatibility (?)
3. **Cost recovery / individual rationality** 😊
4. Revenue adequacy (balanced budget)

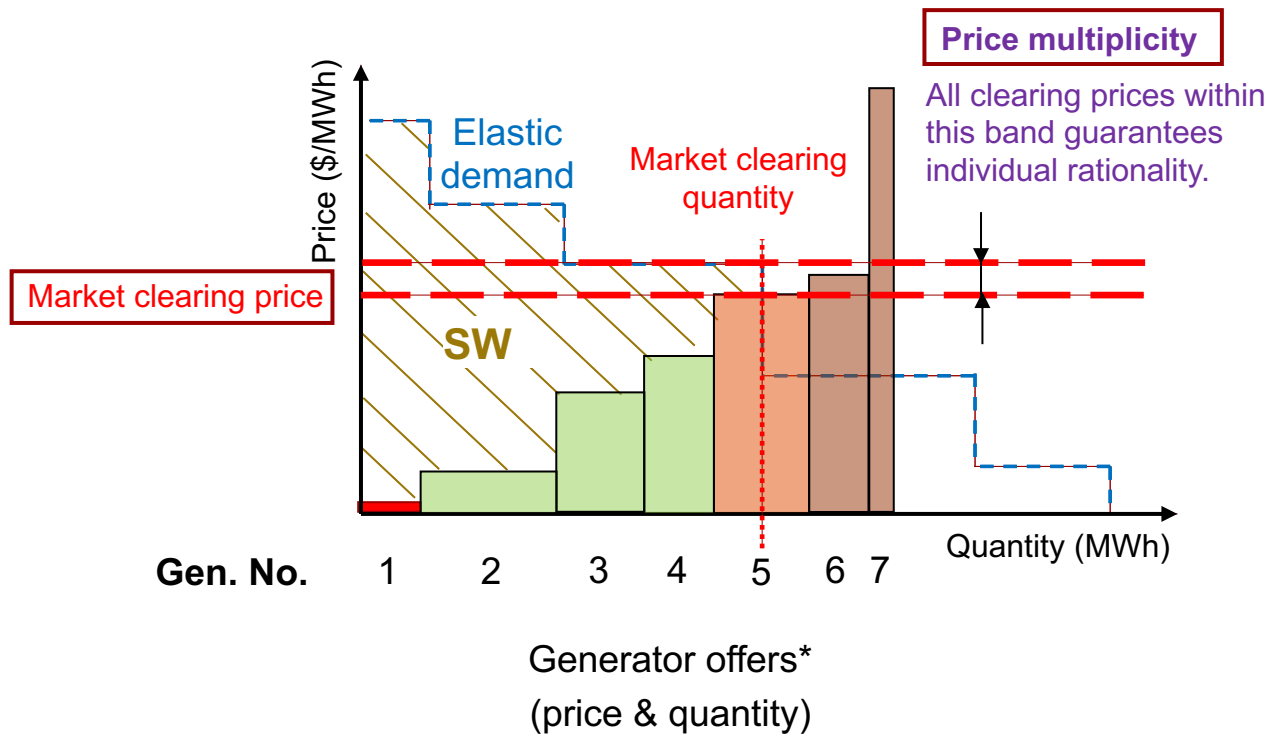
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



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4. **Revenue adequacy (balanced budget)**

The market is **revenue adequate** when the market operator does not suffer a financial deficit, and it is **budget balanced** when the market operator does not have a financial deficit nor an excess.

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



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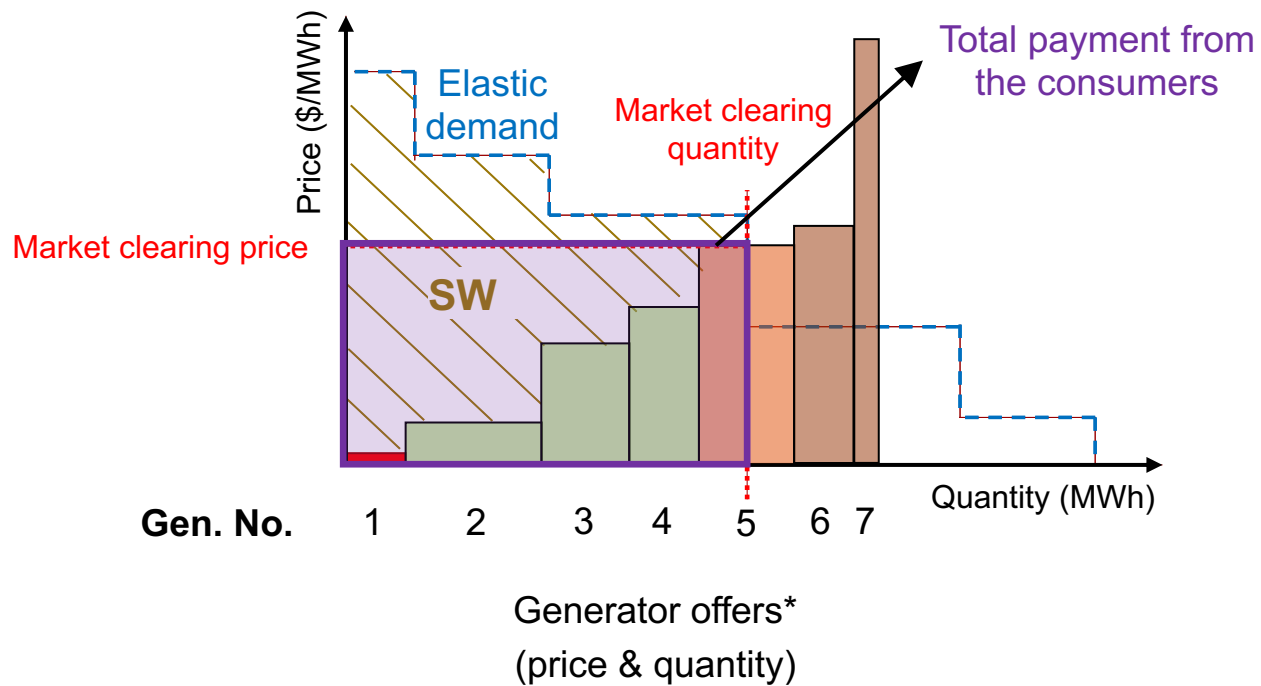
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Is the electricity market under uniform pricing **budget balanced**?

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: **maximizes total social welfare (SW)**



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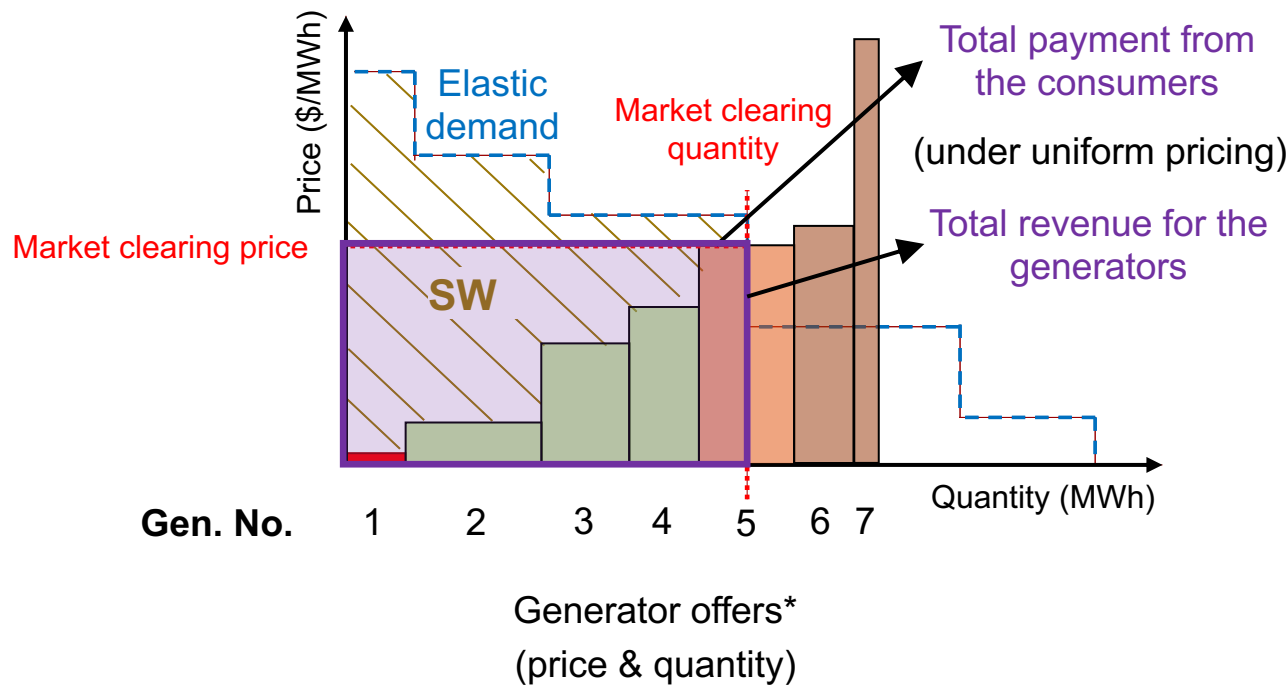
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: maximizes total social welfare (SW)

Method 2: Optimization



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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: maximizes total social welfare (SW)

Method 2: Optimization



*Assumption: all generators are price-takers with truthful offers:
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$$\text{Maximize}_{p_g^G, p_d^D} SW = \sum_d U_d p_d^D - \sum_g C_g p_g^G \quad (1a)$$

subject to:

$$0 \leq p_d^D \leq \bar{P}_d^D \quad \forall d \quad (1b)$$

$$0 \leq p_g^G \leq \bar{P}_g^G \quad \forall g \quad (1c)$$

$$\sum_d p_d^D - \sum_g p_g^G = 0 \quad : \lambda \quad (1d)$$

U_d : bid price of demand d

C_g : offer price of generator g

\bar{P}_d^D : maximum load of demand d

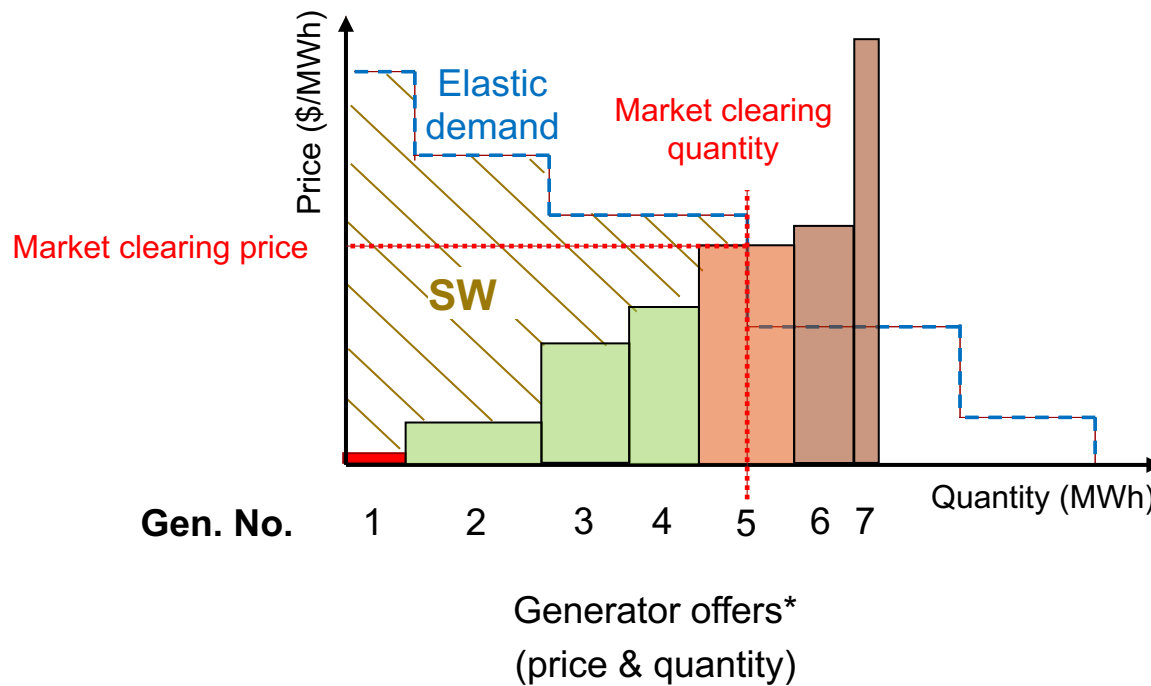
\bar{P}_g^G : capacity of generator g

Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: maximizes total social welfare (SW)



Method 2: Optimization



*Assumption: all generators are price-takers with truthful offers:
offer prices = marginal costs and offer quantities = true capacities

$$\text{Maximize}_{p_g^G, p_d^D} SW = \sum_d U_d p_d^D - \sum_g C_g p_g^G \quad (1a)$$

subject to:

$$0 \leq p_d^D \leq \bar{P}_d^D \quad \forall d \quad (1b)$$

$$0 \leq p_g^G \leq \bar{P}_g^G \quad \forall g \quad (1c)$$

$$\sum_d p_d^D - \sum_g p_g^G = 0 \quad : \lambda \quad (1d)$$

U_d : bid price of demand d

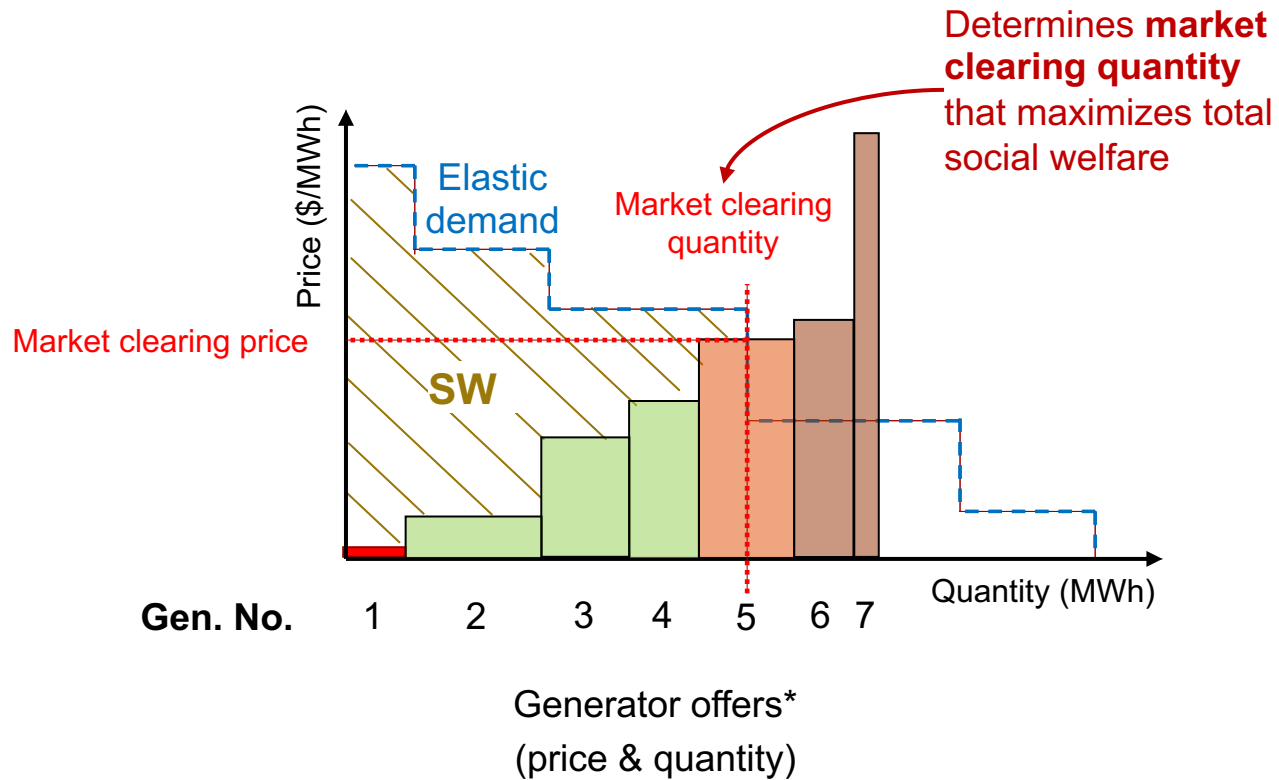
C_g : offer price of generator g

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Electricity Market Clearing under Uniform Pricing

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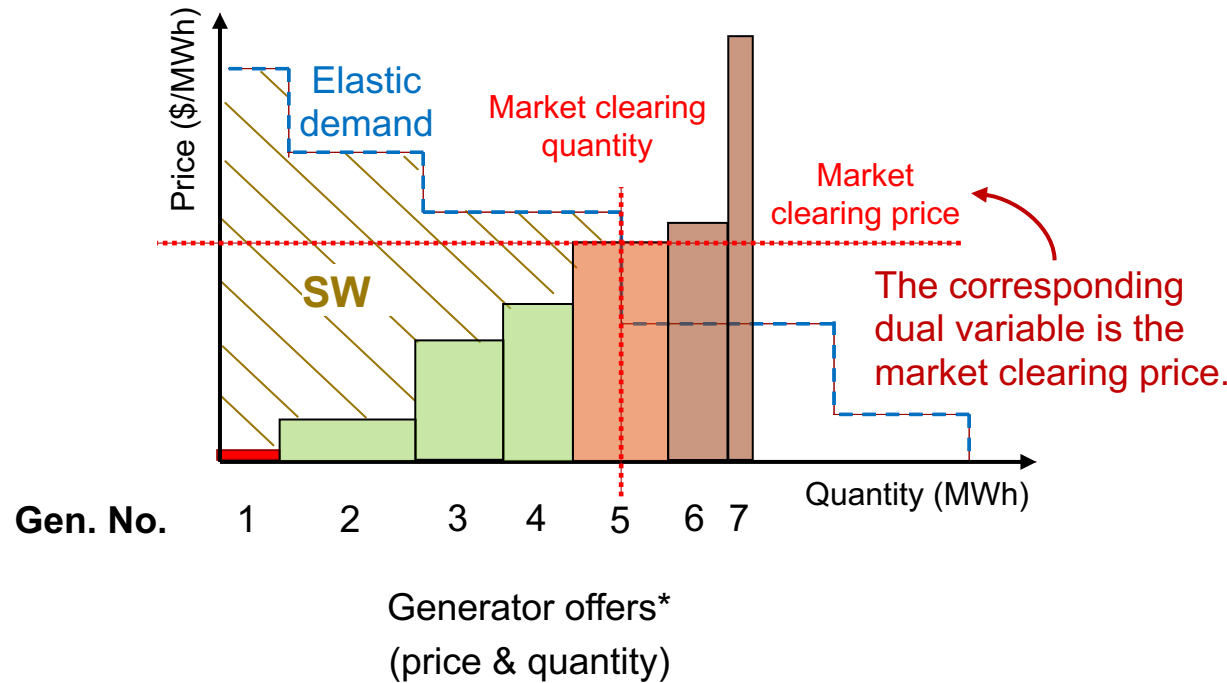
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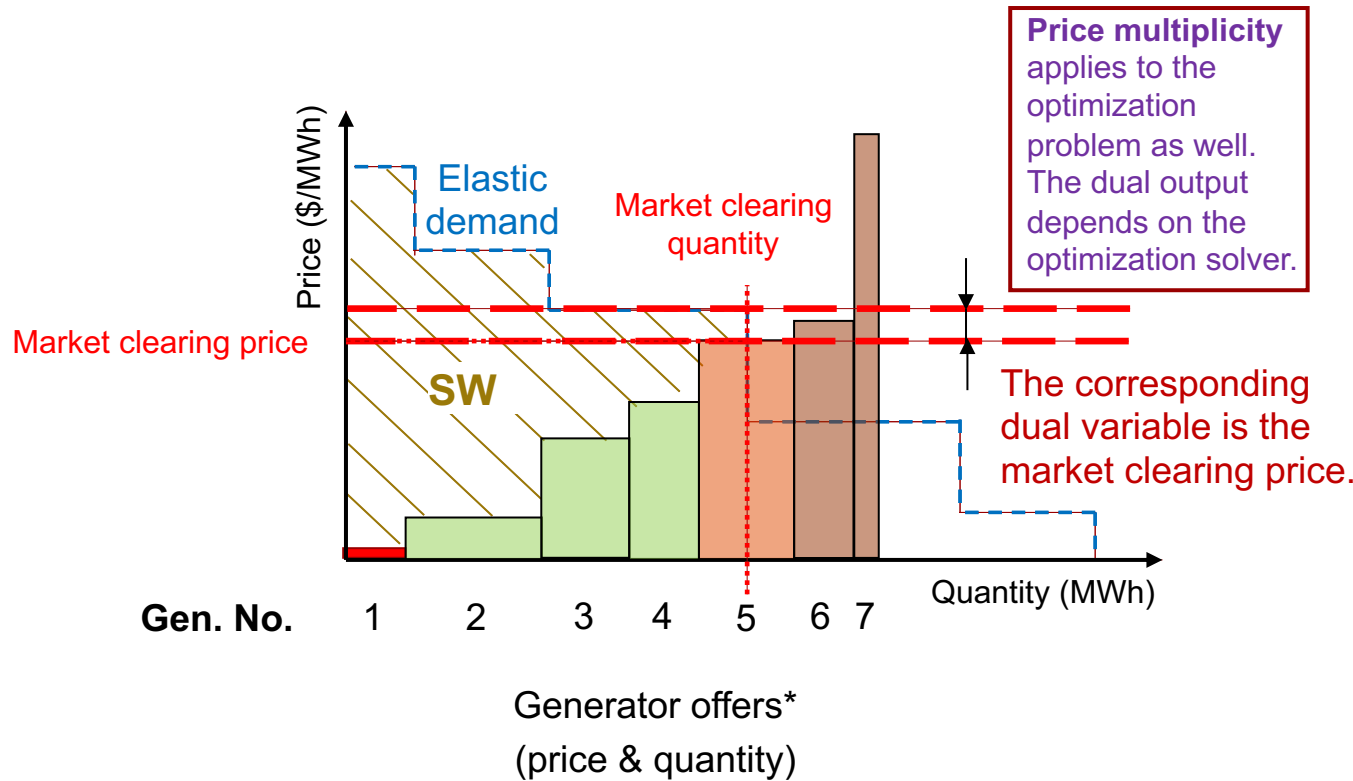
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Not in the
objective function

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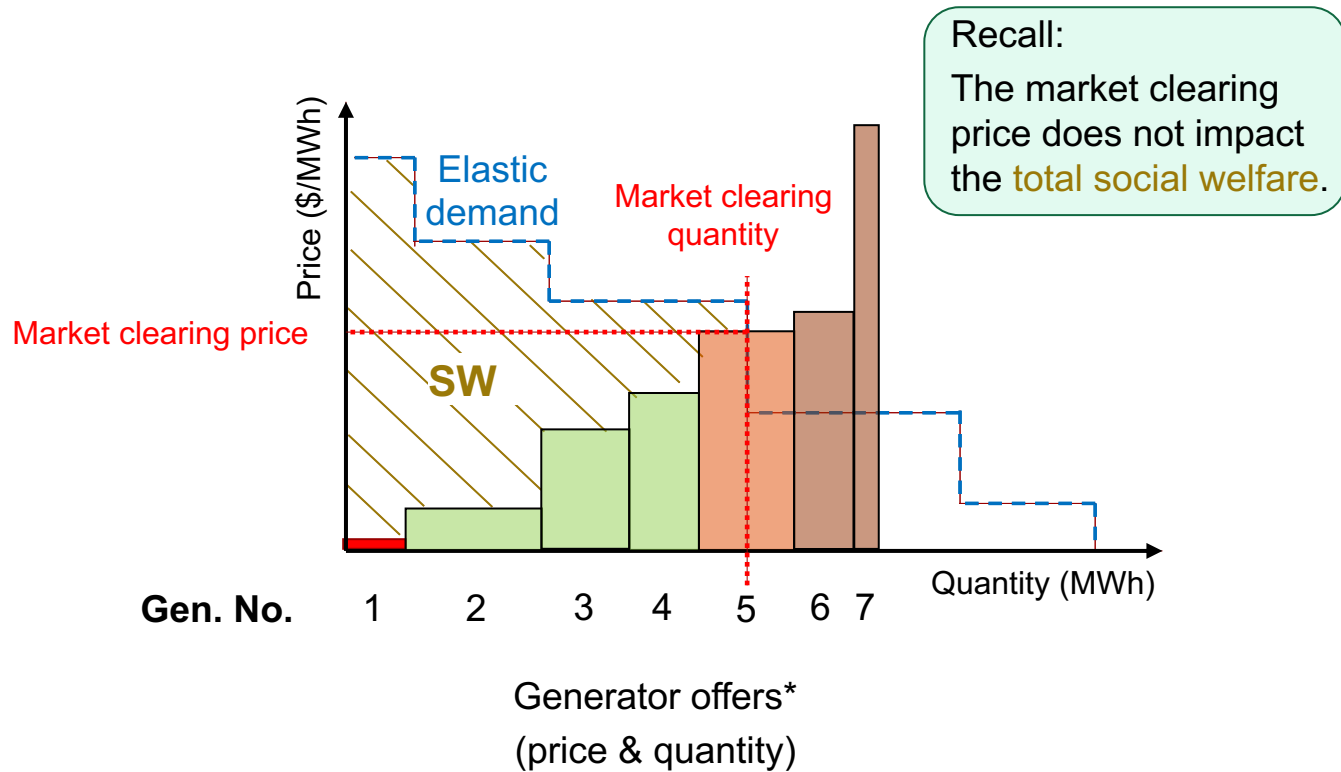
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Electricity Market Clearing under Uniform Pricing

Method 1: Merit-Order: maximizes total social welfare (SW) \equiv Method 2: Optimization

Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency (?)
2. Incentive compatibility (?)
3. Cost recovery / individual rationality 😊
4. Revenue adequacy (balanced budget) 😊

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Electricity Market Clearing under Uniform Pricing

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Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency (?)
2. Incentive compatibility (?)
3. Cost recovery / individual rationality 😊
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Can you prove this?

$$\text{Maximize}_{p_g^G, p_d^D} \quad SW = \sum_d U_d p_d^D - \sum_g C_g p_g^G \quad (1a)$$

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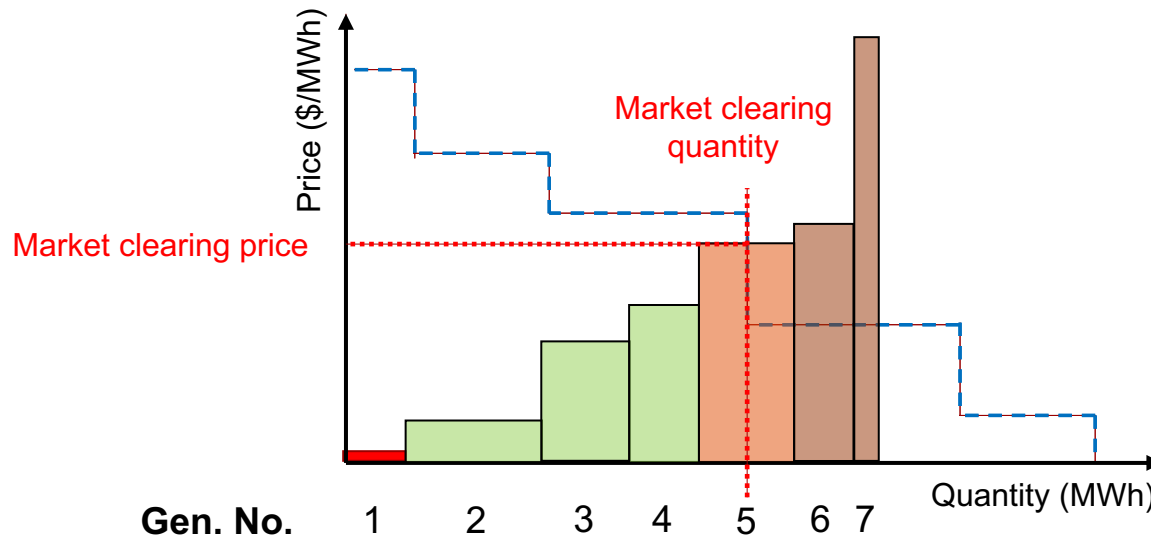
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Strategic Players in the Market

Electricity market clearing with the merit-order

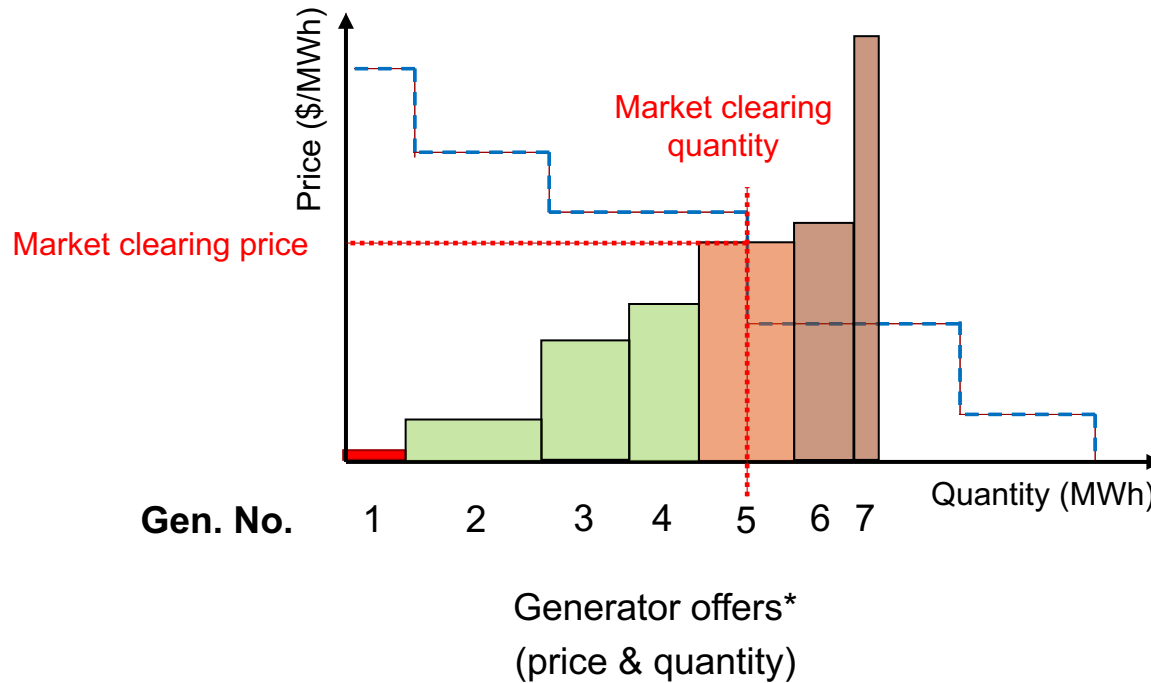


Generator offers*
(price & quantity)

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Strategic Players in the Market

Electricity market clearing with the merit-order



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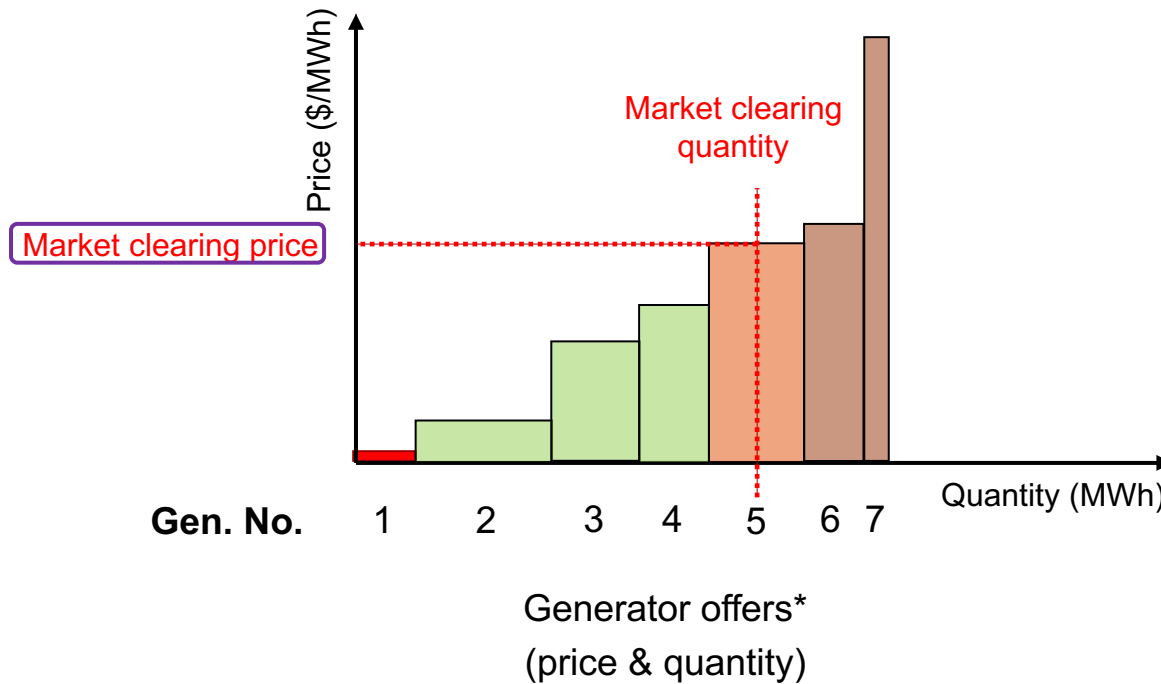
Recall from **Lecture 7**:

Price-takers do *not* model in their offering strategies how they impact the market clearing outcome.

What does this mean in practice?

Strategic Players in the Market

Electricity market clearing with the merit-order



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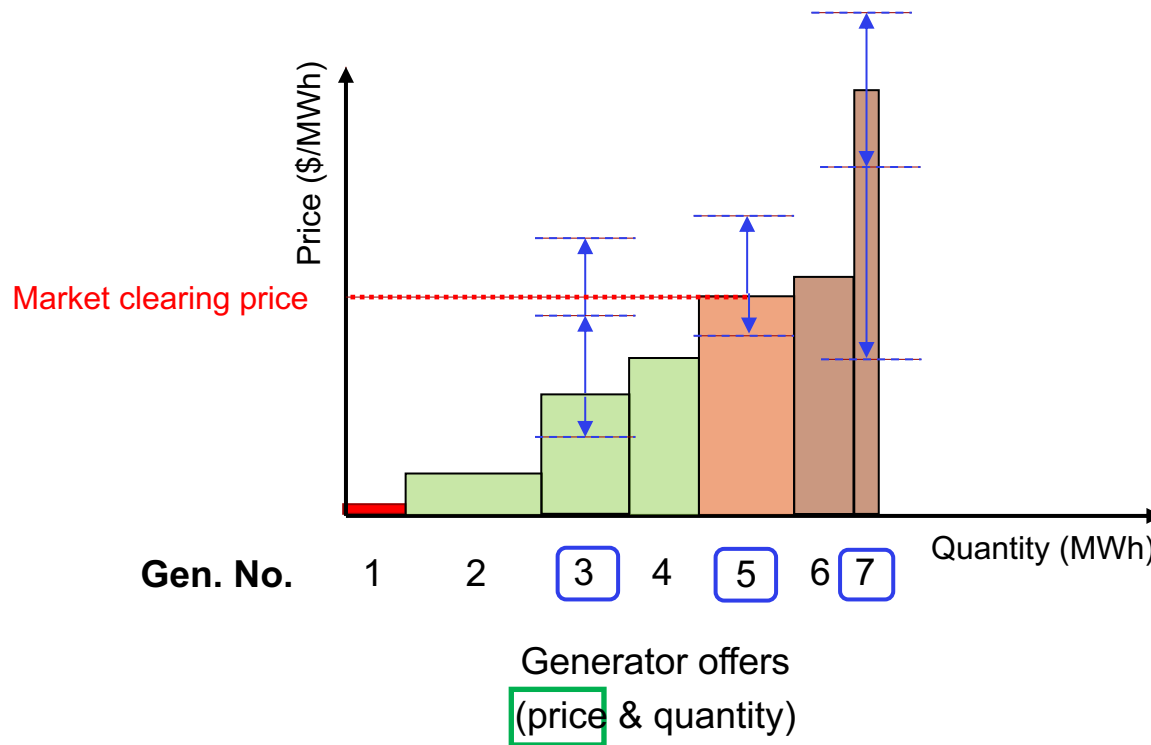
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Strategic Players in the Market

Electricity market clearing with the merit-order



(All the **offer prices** shown are the generators' **marginal costs**)

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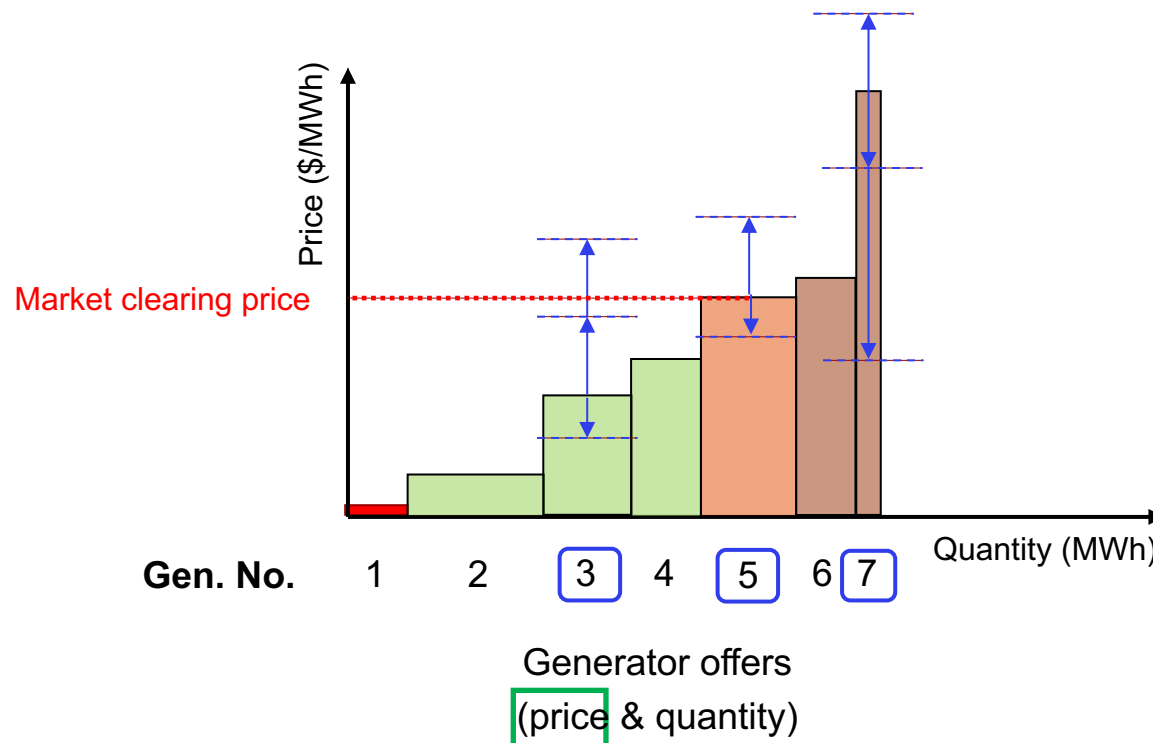
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| Gen. No. | Profit w from truthful bidding | profit \bar{w} from over-bidding | profit \underline{w} from under-bidding |
|----------|----------------------------------|------------------------------------|---|
| 3 | $w_3 > 0$ | | |
| 5 | $w_5 = 0$ | | |
| 7 | $w_7 = 0$ | | |

Strategic Players in the Market

Electricity market clearing with the merit-order



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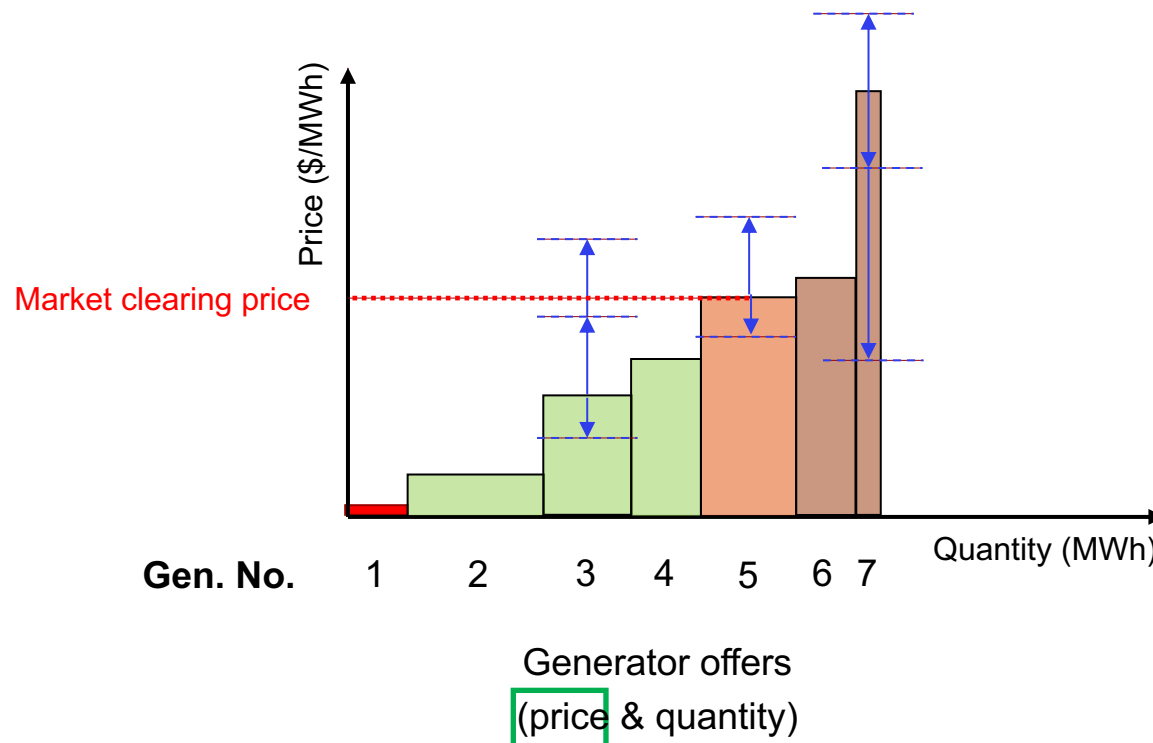
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Strategic Players in the Market

Electricity market clearing with the merit-order



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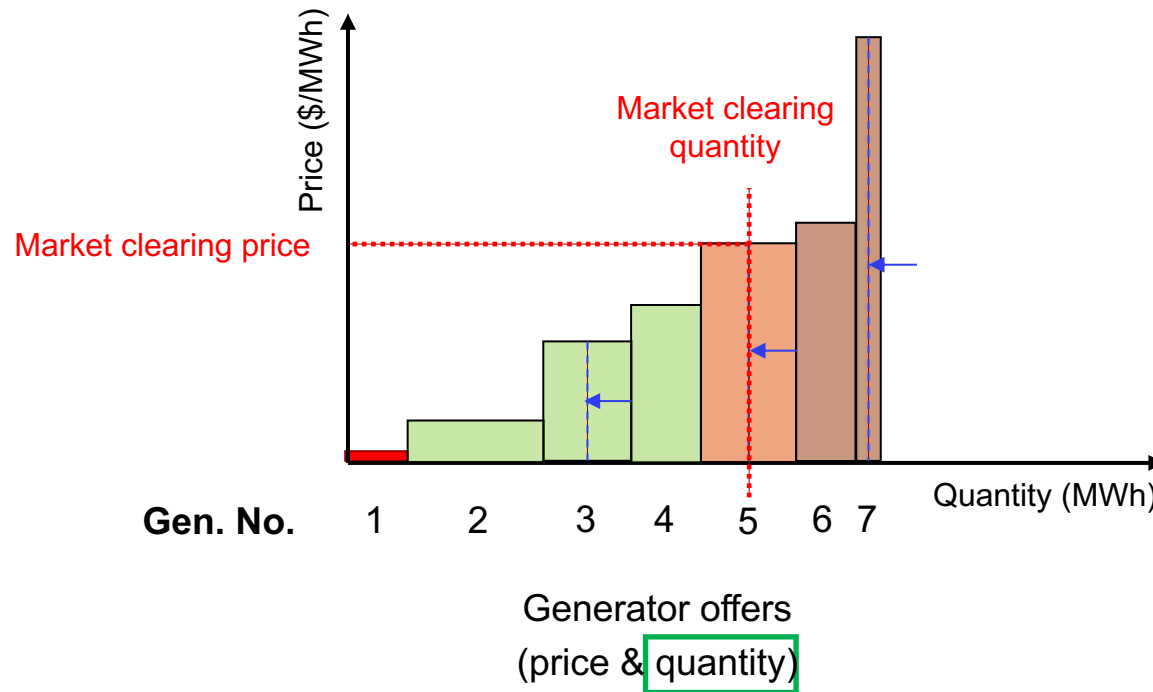
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- Untruthful bidding cannot lead to increased profits, so agents would offer with their true marginal costs!

Strategic Players in the Market

Electricity market clearing with the merit-order



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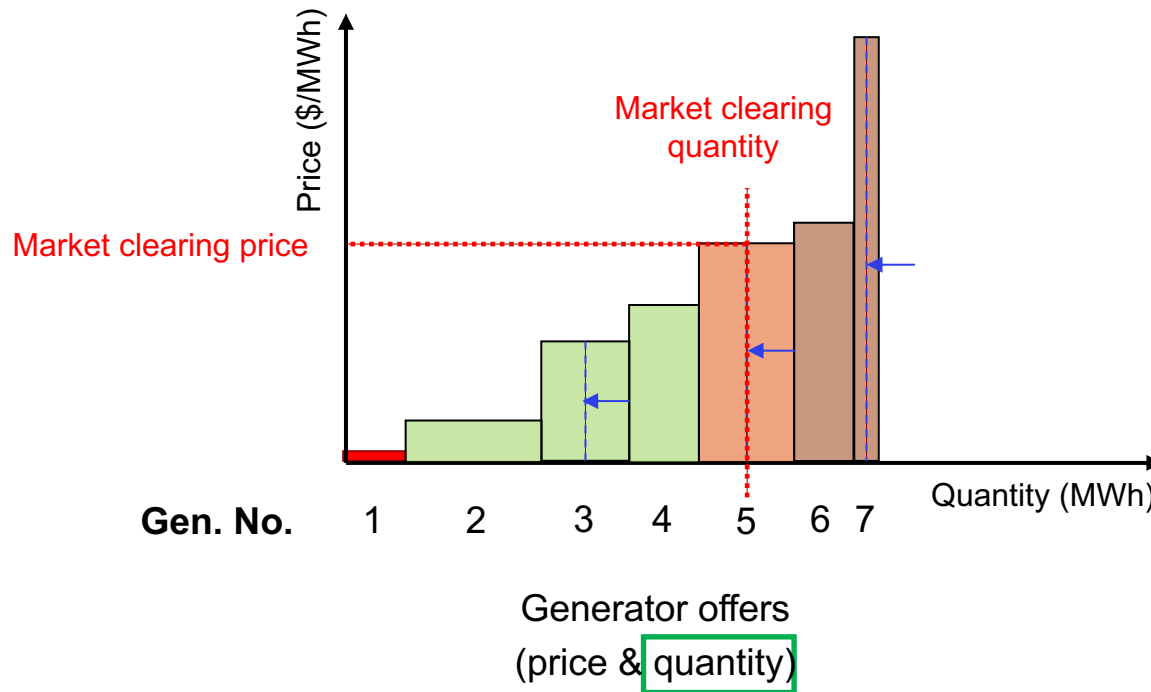
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| 5 | $w_5 = 0$ | N/A | |
| 7 | $w_7 = 0$ | N/A | |

(All the **offer quantities** shown are the generators' **true capacities**)

Strategic Players in the Market

Electricity market clearing with the merit-order



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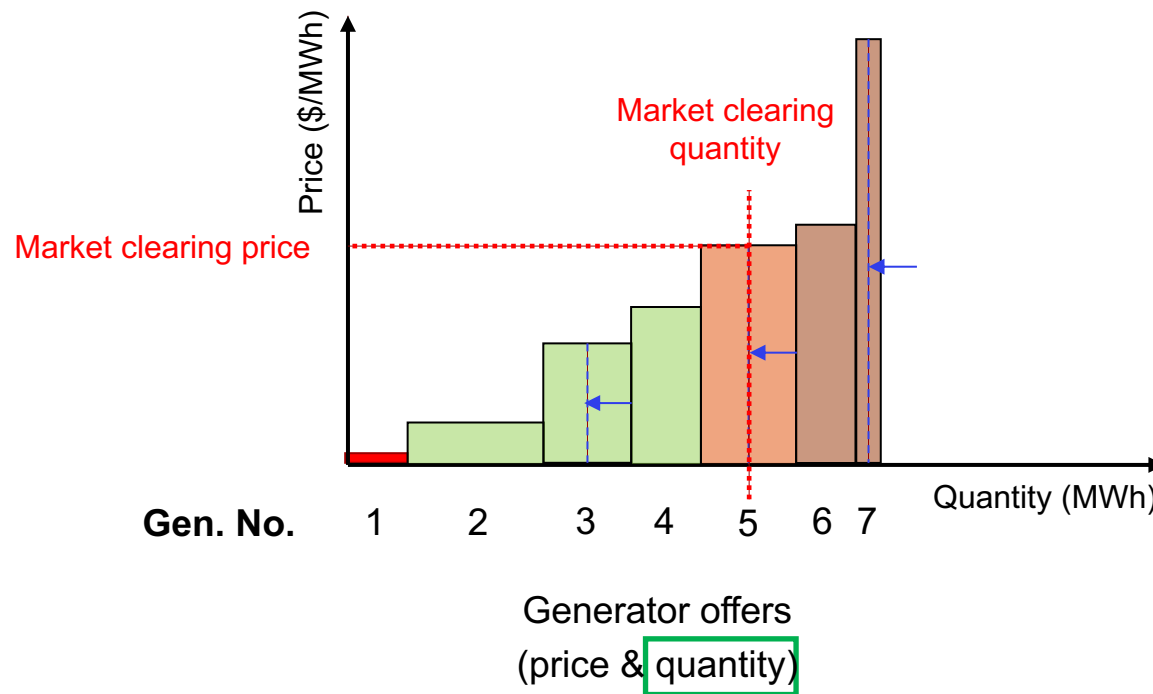
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- Agents would offer with their true capacities.

(All the **offer quantities** shown are the generators' **true capacities**)

Strategic Players in the Market

Electricity market clearing with the merit-order



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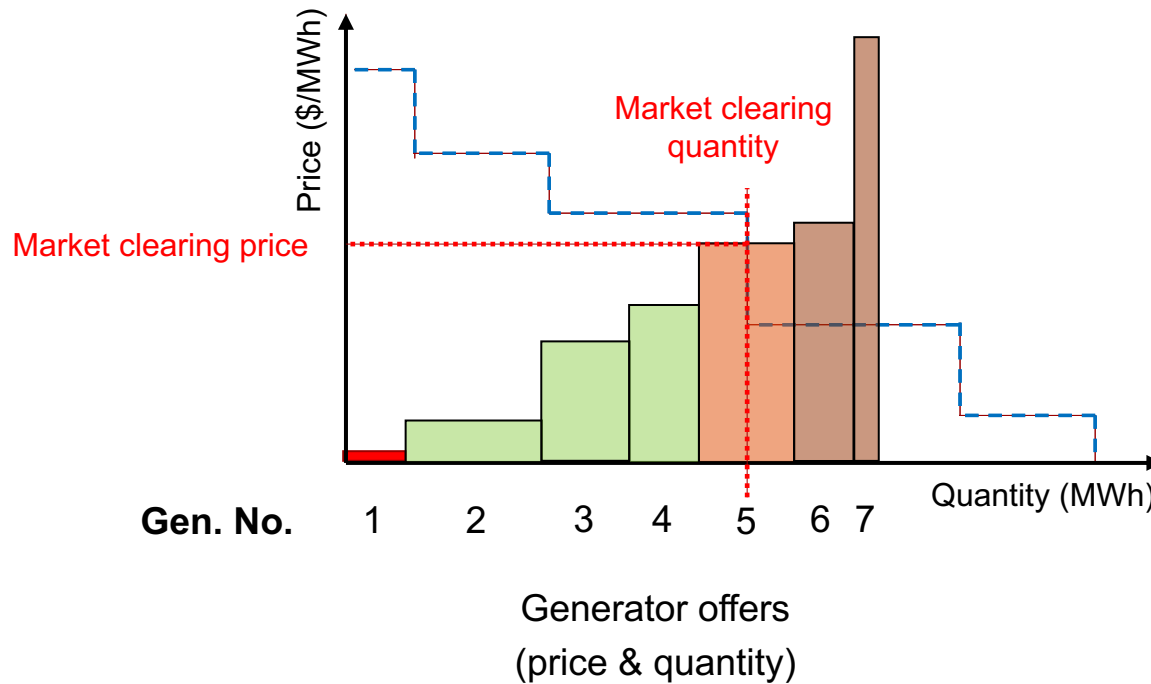
What does this mean in practice?

- From the generator's perspective, the market clearing price is a parameter.

All price-taker generators would offer in the market with their truthful marginal costs of production and truthful (forecast) capacities

Strategic Players in the Market

Electricity market clearing with the merit-order



(All the **offers** (price & quantity) shown are the generators' **truthful offers**)

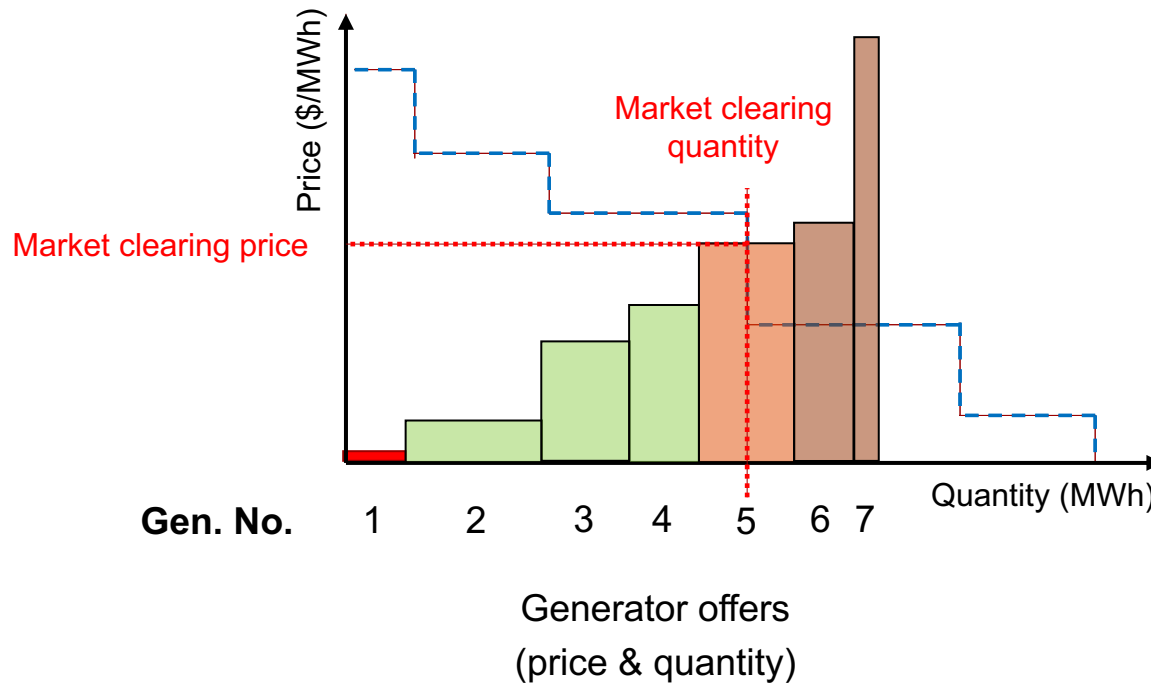
What if...

The agents are **price-makers**, which means that they ***anticipate changes*** in the clearing outcome based on their own bids given information about the demand curve and other agents' bids.

Which generators can be the price-makers?

Strategic Players in the Market

Electricity market clearing with the merit-order



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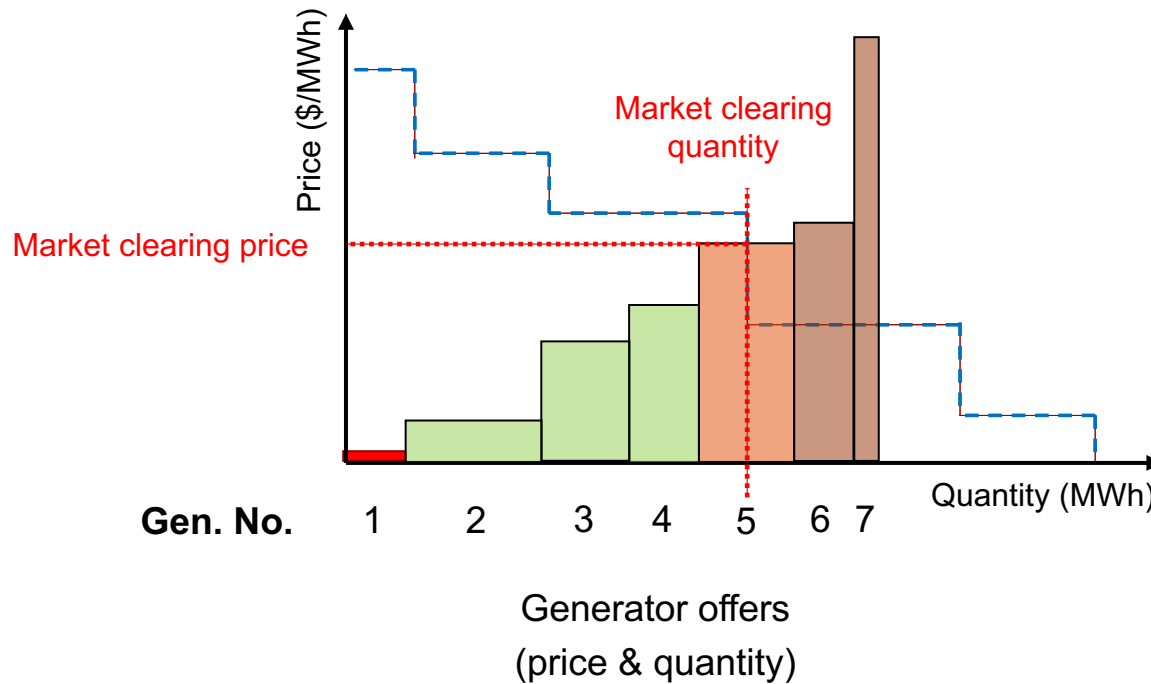
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Which generators can be the price-makers?

- All of them!

Strategic Players in the Market

Electricity market clearing with the merit-order



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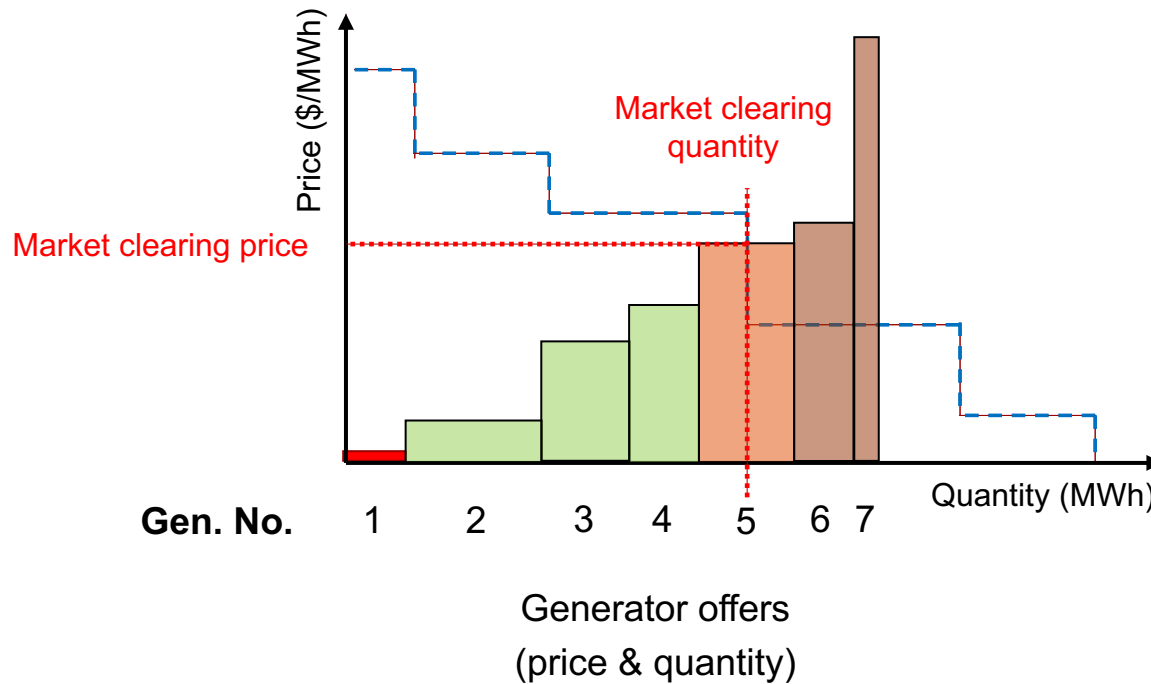
The agents are **price-makers**, which means that they *anticipate changes* in the clearing outcome based on their own bids given information about the demand curve and other agents' bids.

Which generators can gain higher profits by submitting untruthful offers? How?

(All the **offers** (price & quantity) shown are the generators' **truthful offers**)

Strategic Players in the Market

Electricity market clearing with the merit-order



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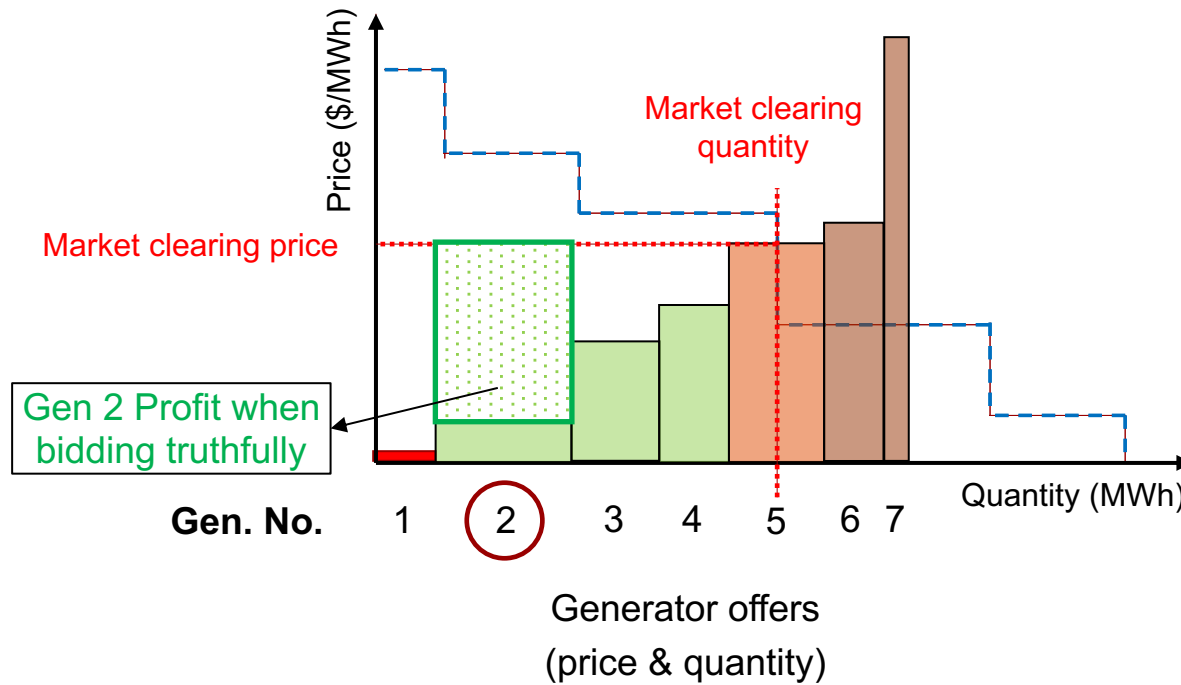
Which generators can gain higher profits by submitting untruthful offers? How?

- Individually, generators 1-5 *may* gain higher profits by over-bidding their price or under-bidding their capacities, e.g., Gen. 2.

(All the **offers** (price & quantity) shown are the generators' **truthful offers**)

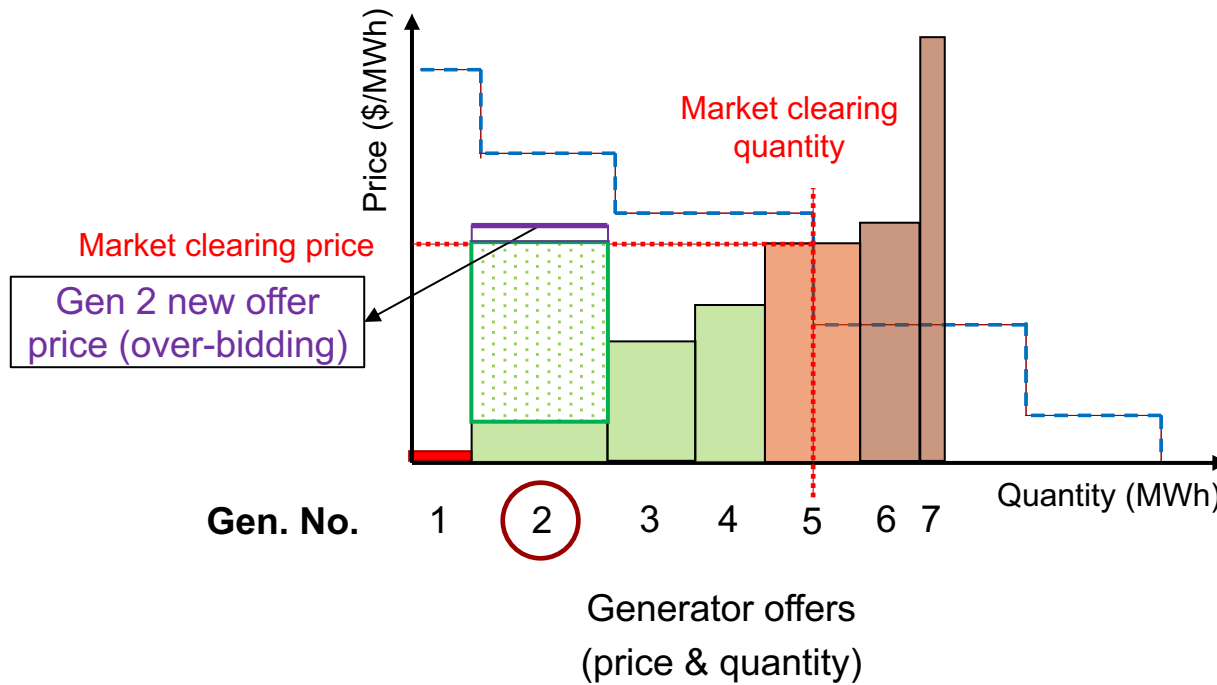
Strategic Players in the Market

Electricity market clearing with the merit-order



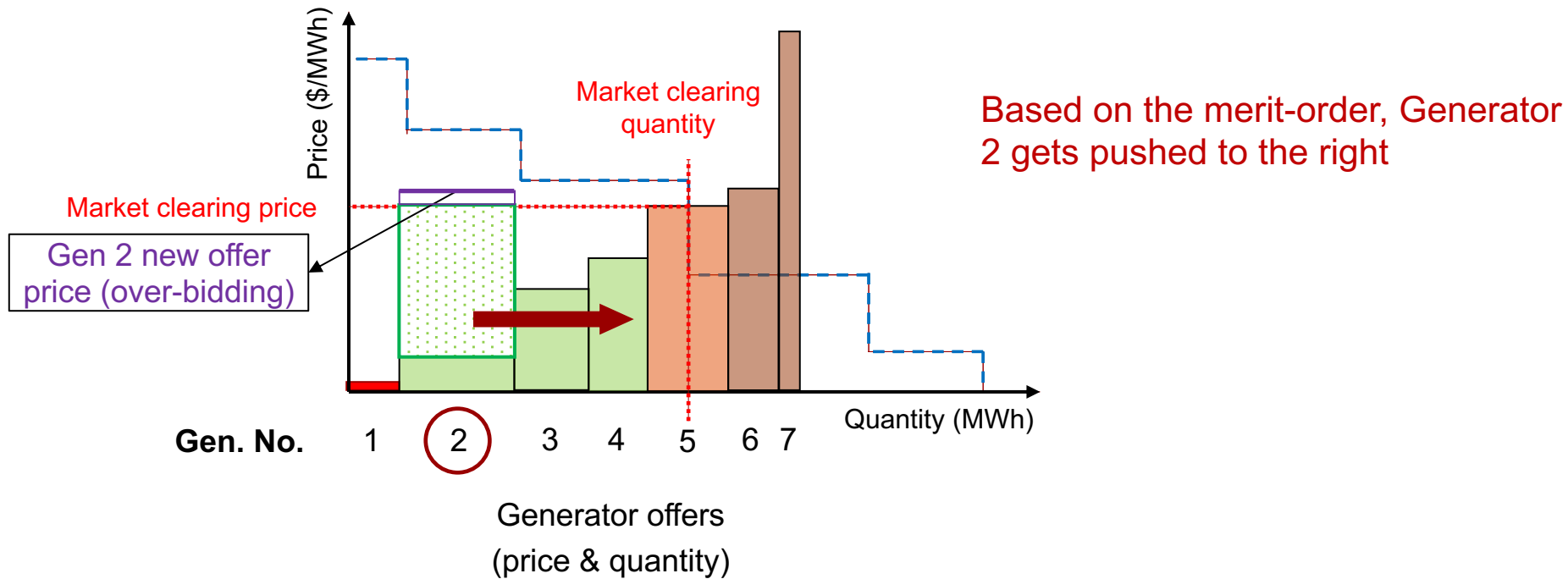
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Strategic Players in the Market

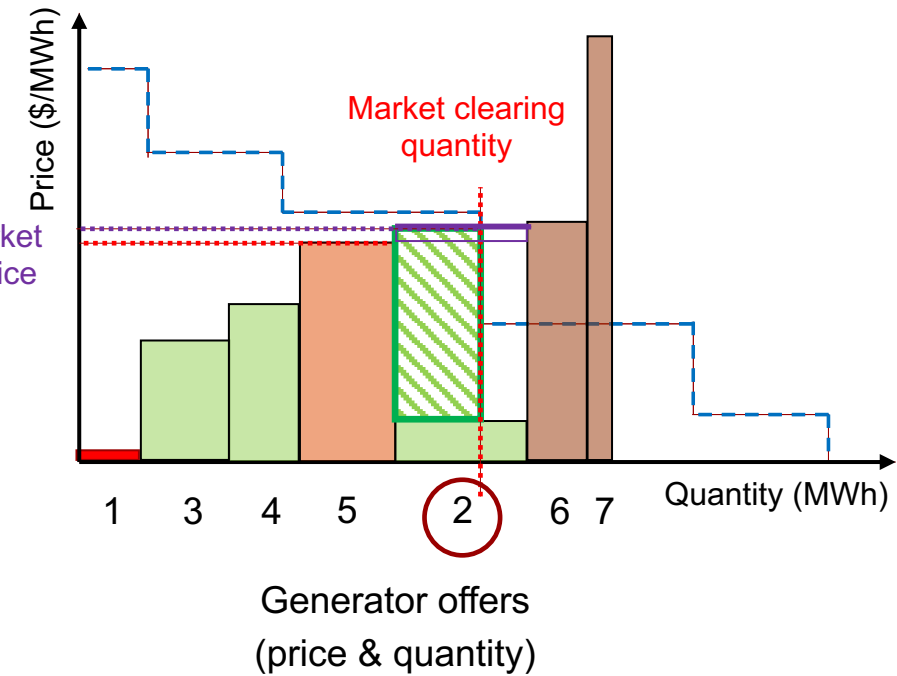
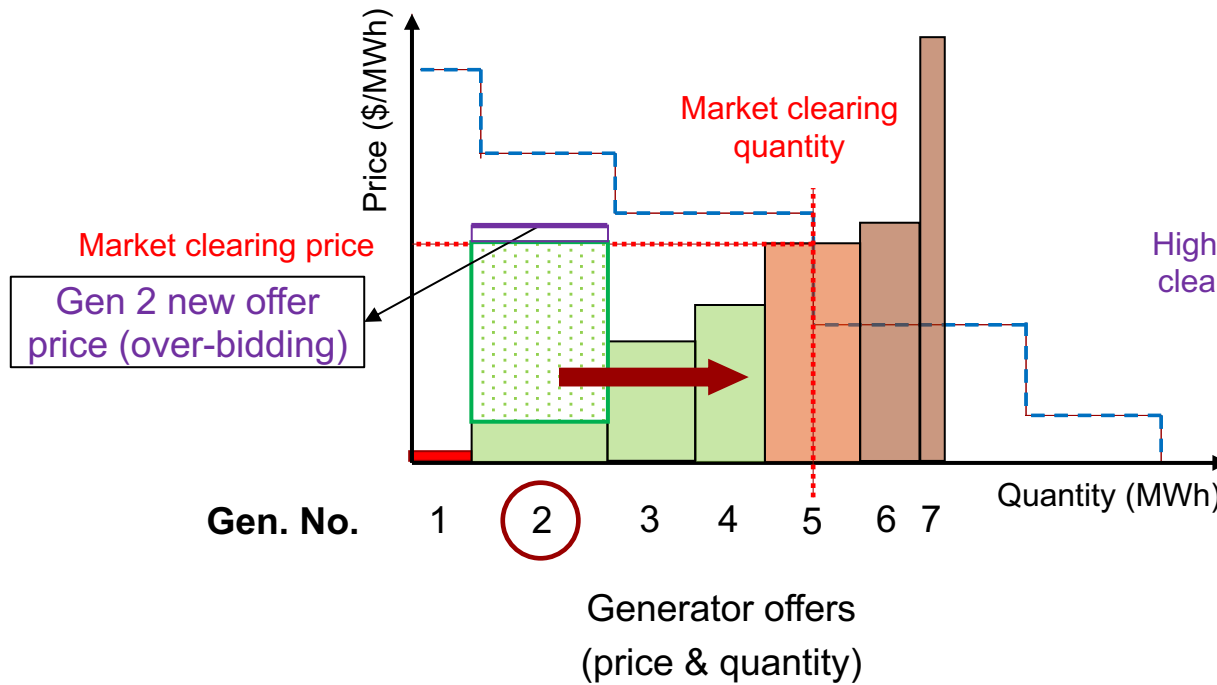
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Strategic Players in the Market

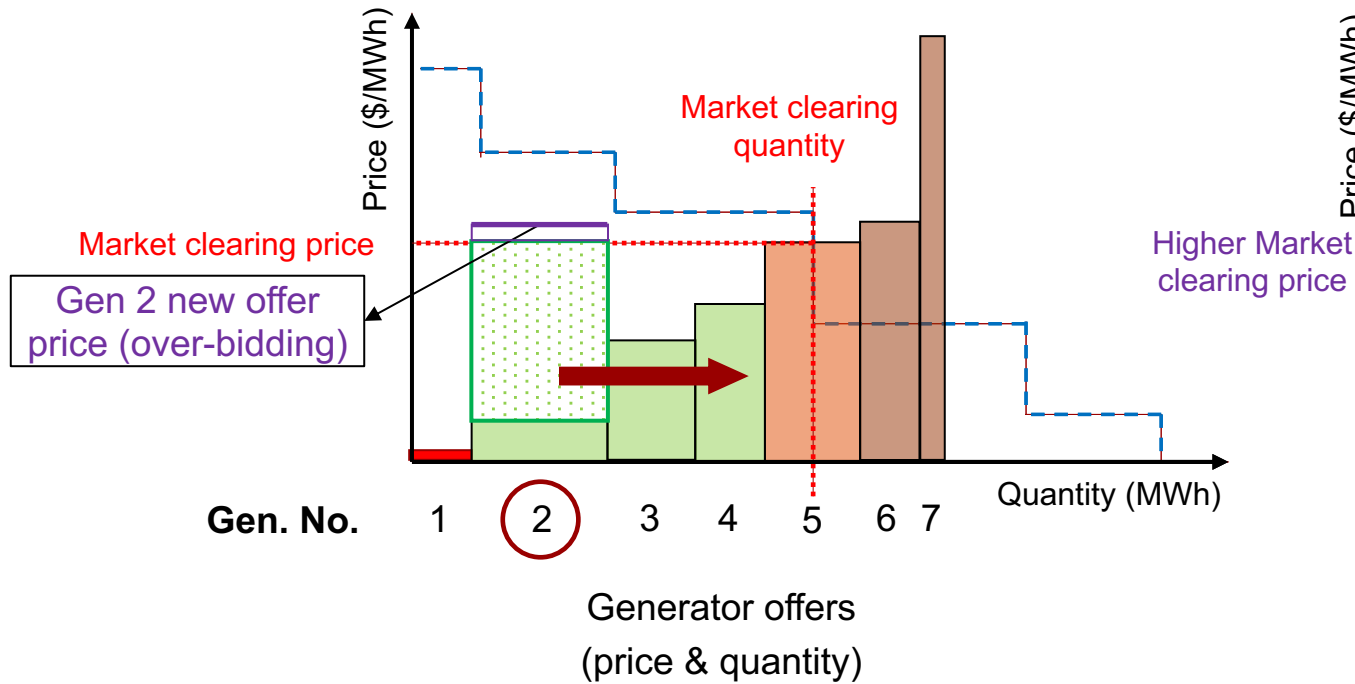
Electricity market clearing with the merit-order

What happens to the profit of Gen 2?



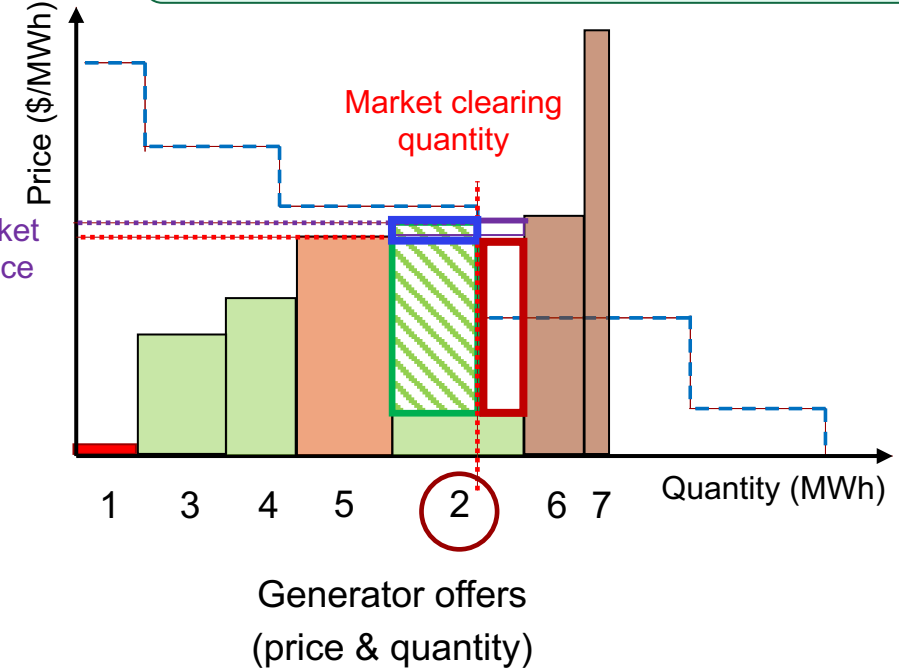
Strategic Players in the Market

Electricity market clearing with the merit-order



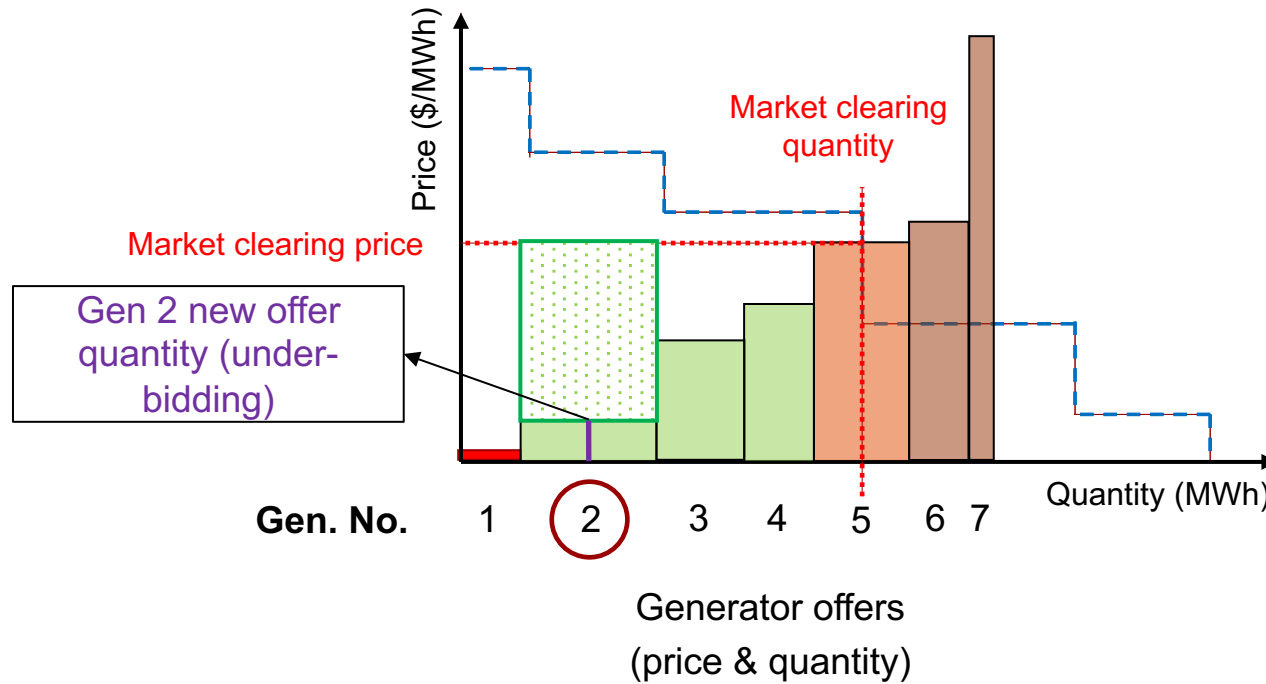
What happens to the profit of Gen 2?

Higher market clearing price but lower quantity
--> **possible increase** in profit



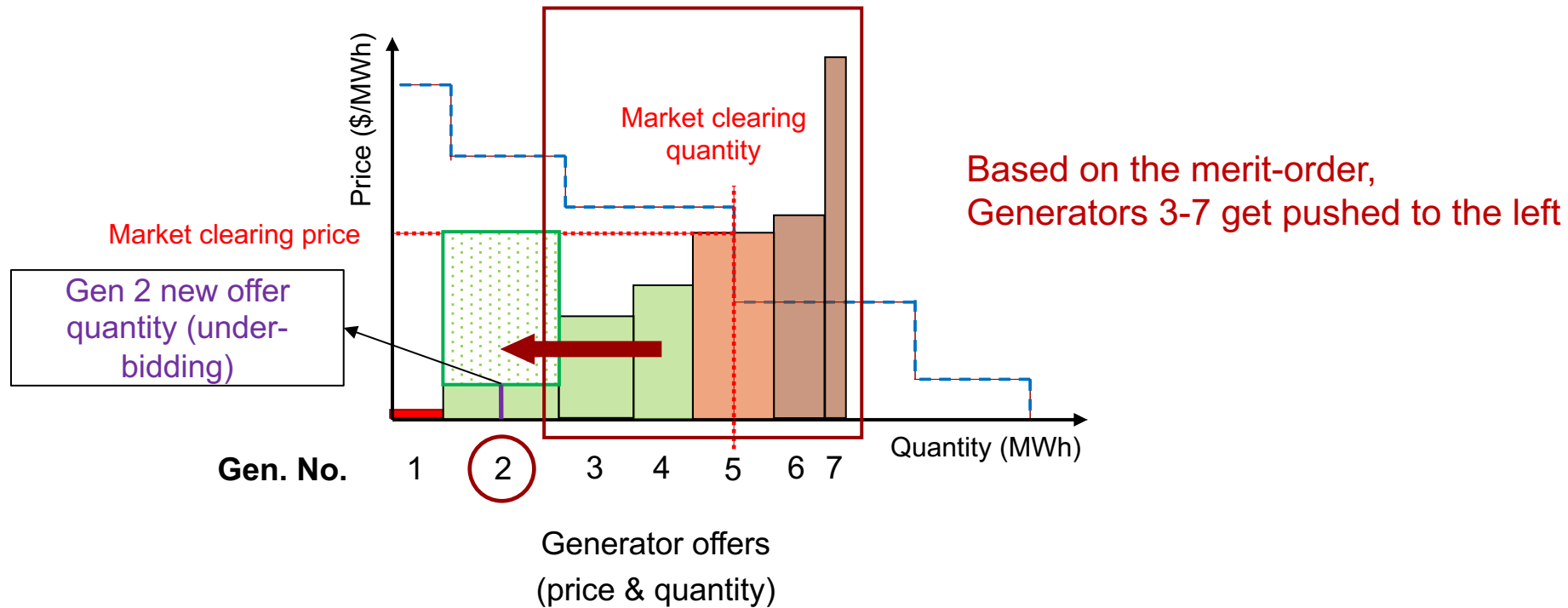
Strategic Players in the Market

Electricity market clearing with the merit-order



Strategic Players in the Market

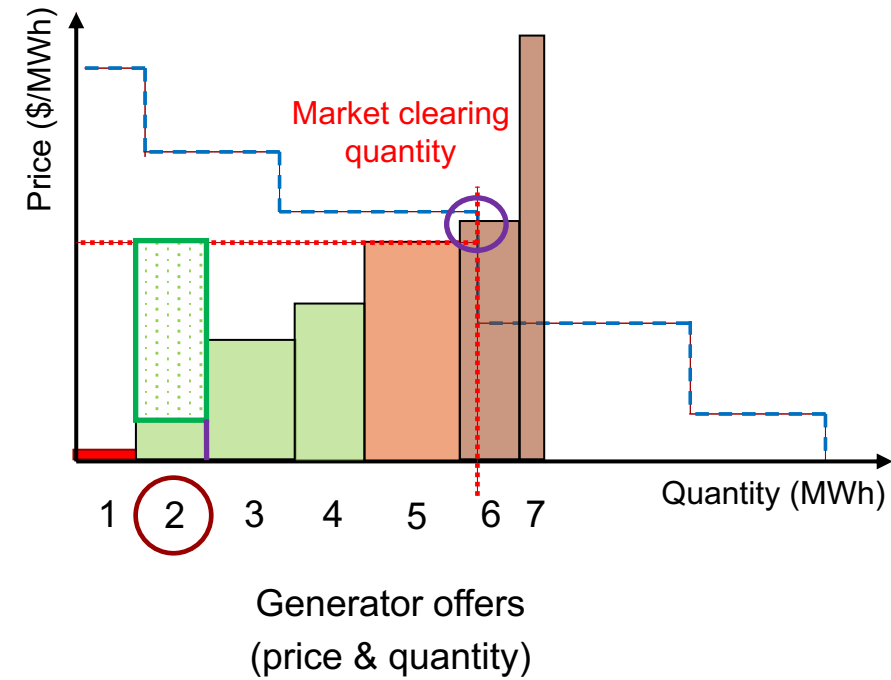
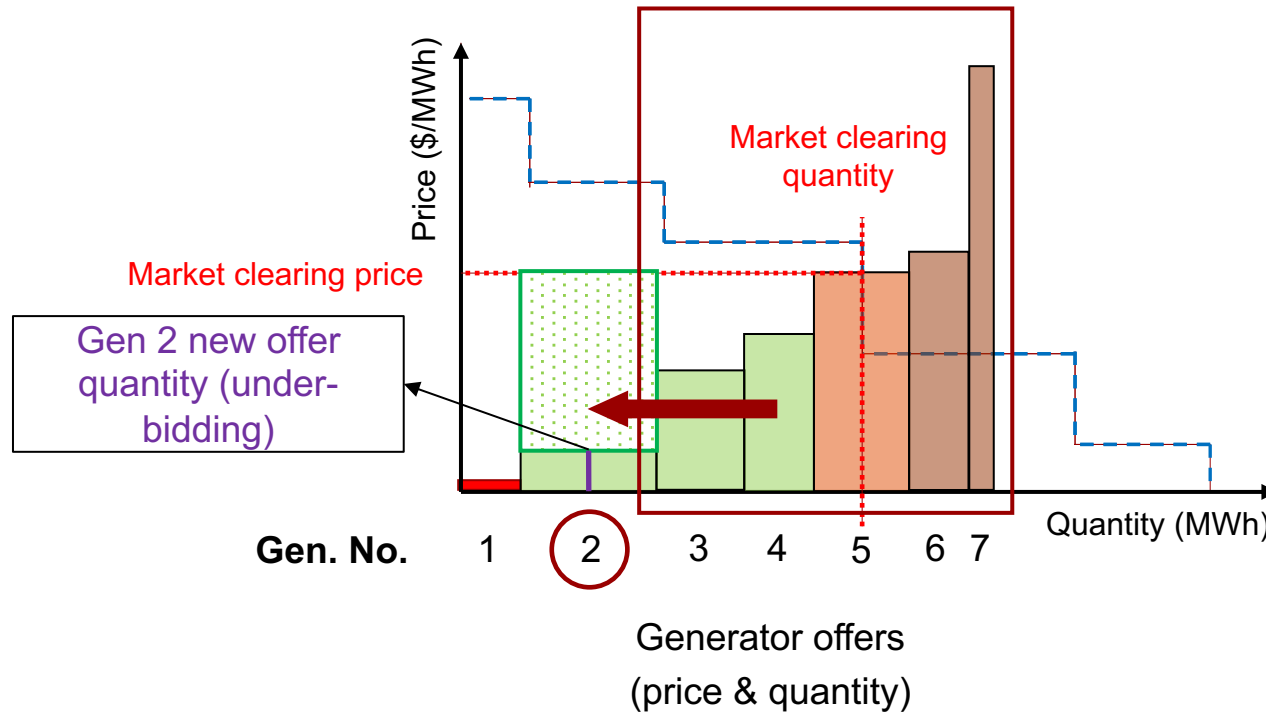
Electricity market clearing with the merit-order



Strategic Players in the Market

Electricity market clearing with the merit-order

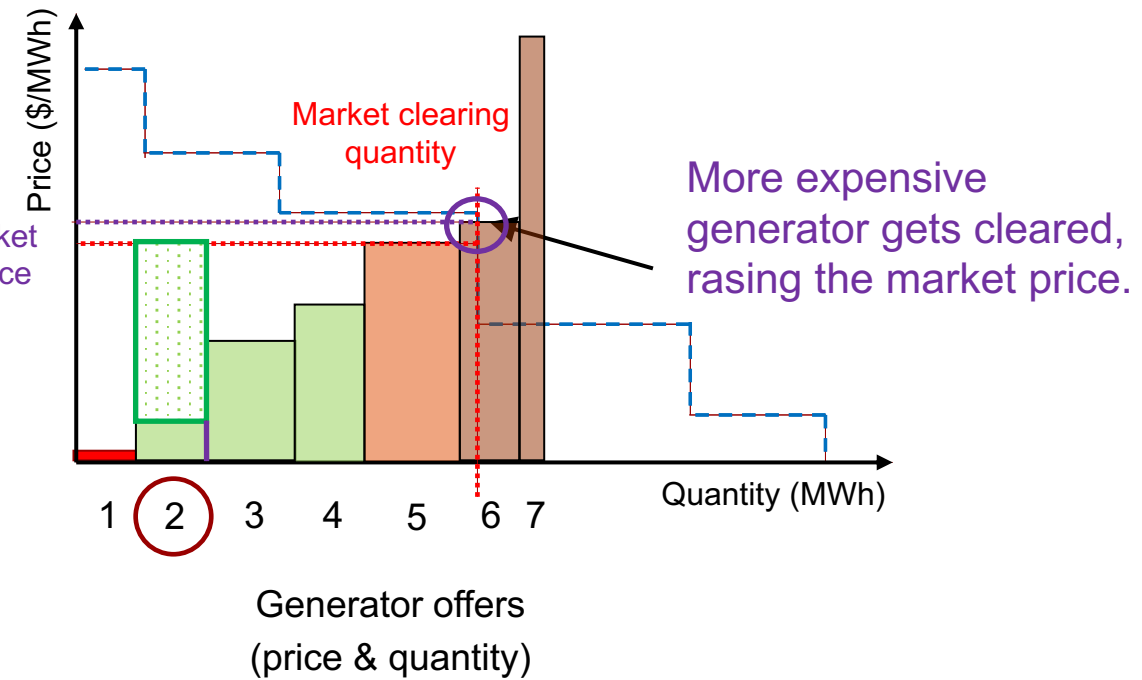
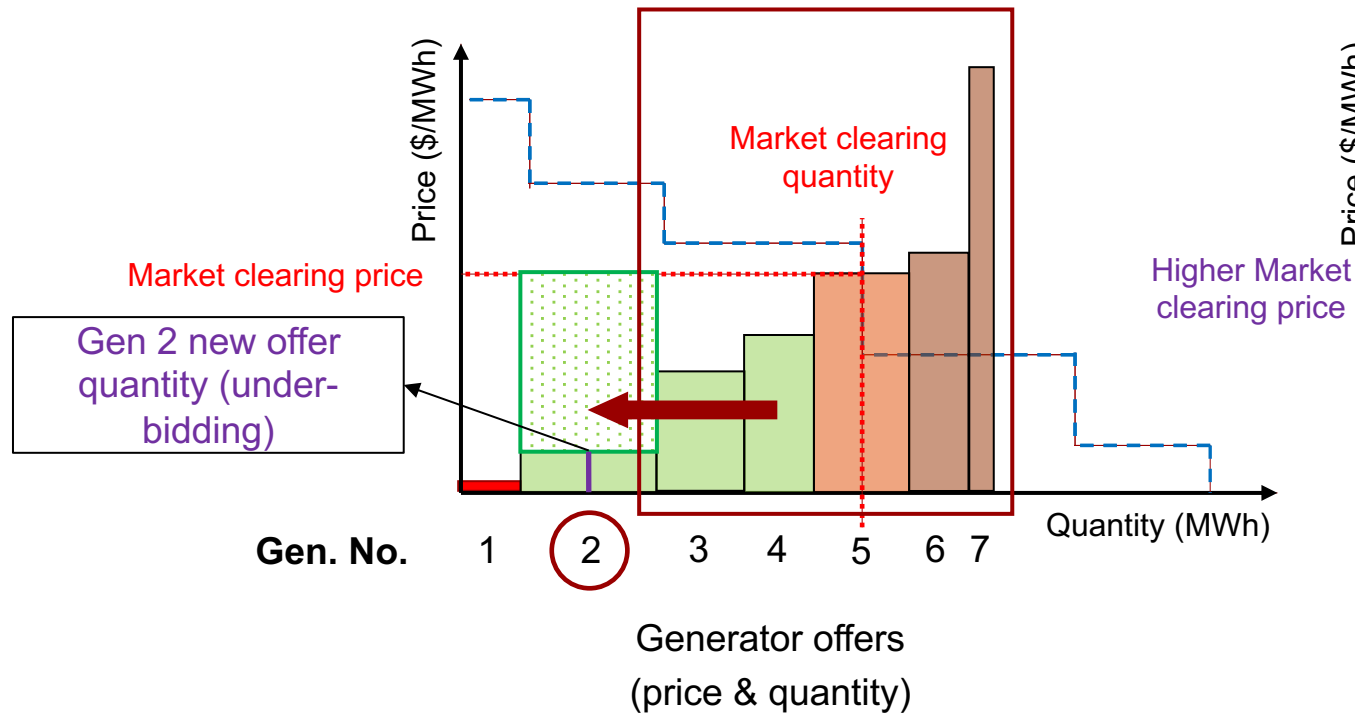
What happens to the profit of Gen 2?



Strategic Players in the Market

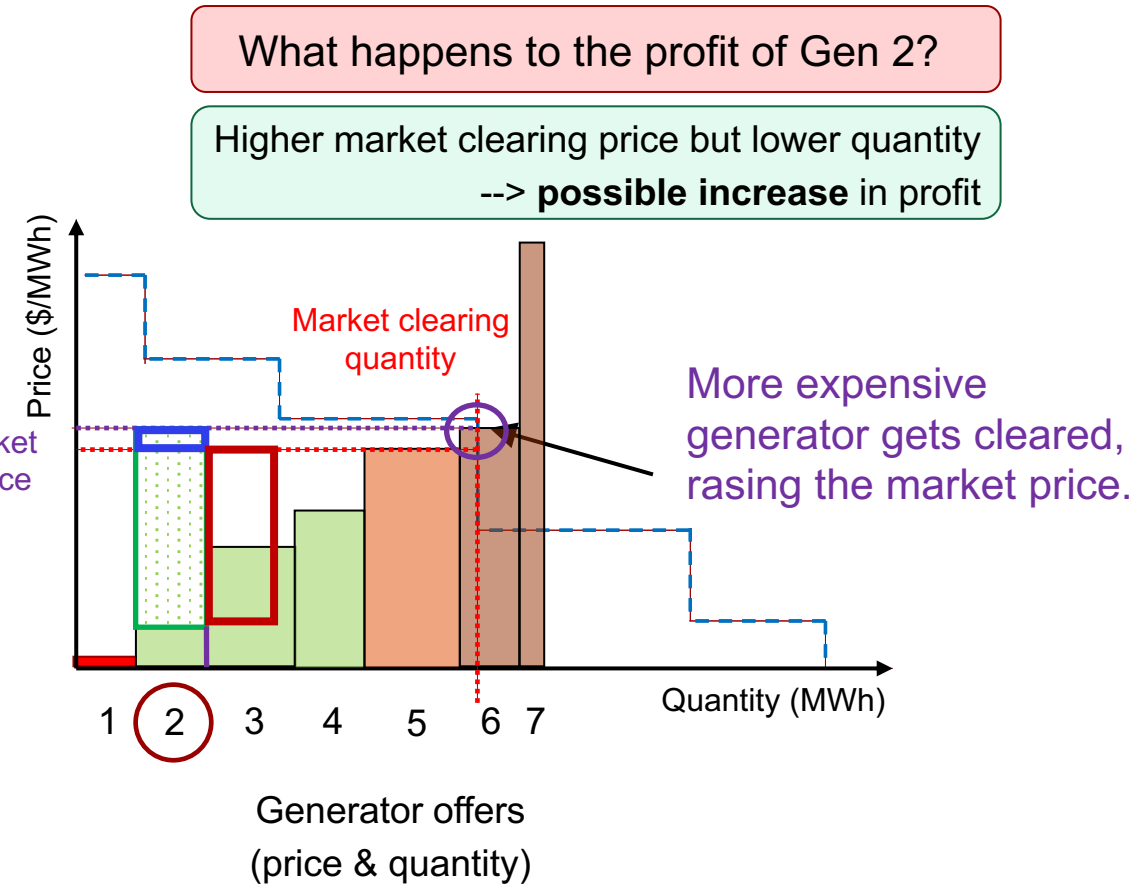
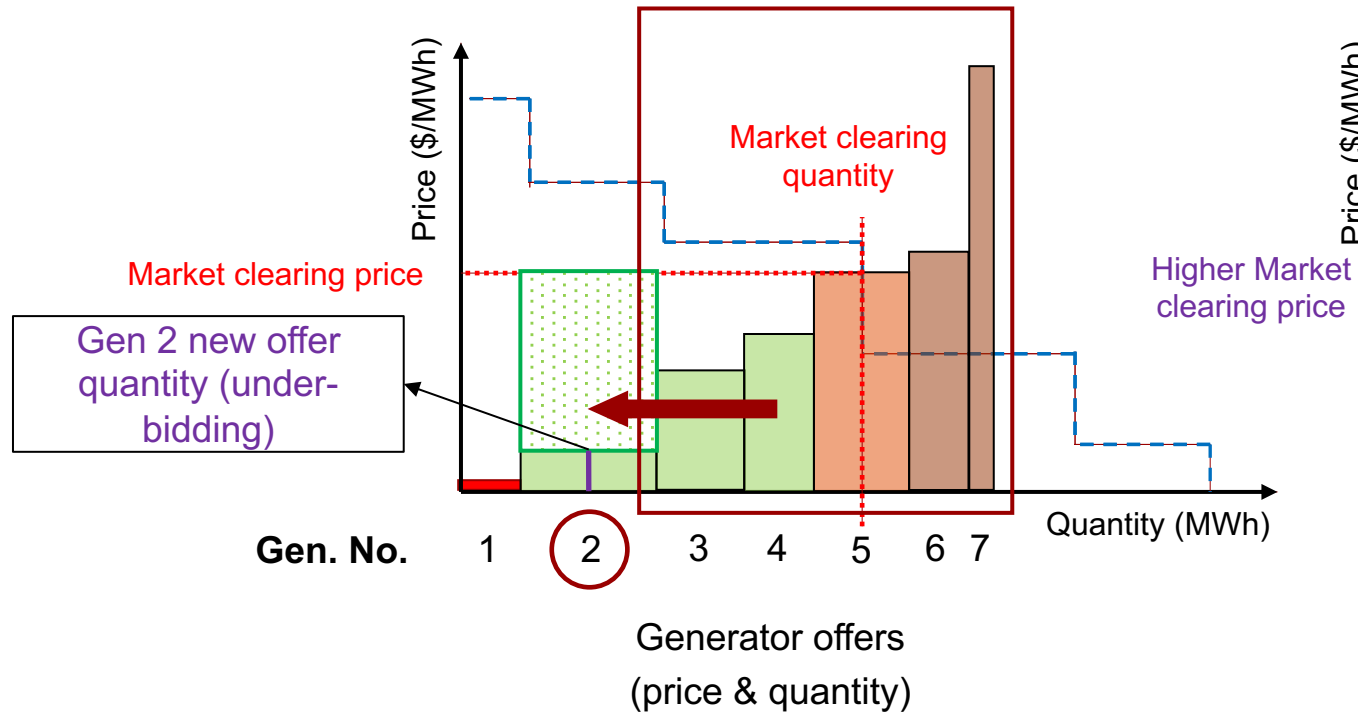
Electricity market clearing with the merit-order

What happens to the profit of Gen 2?



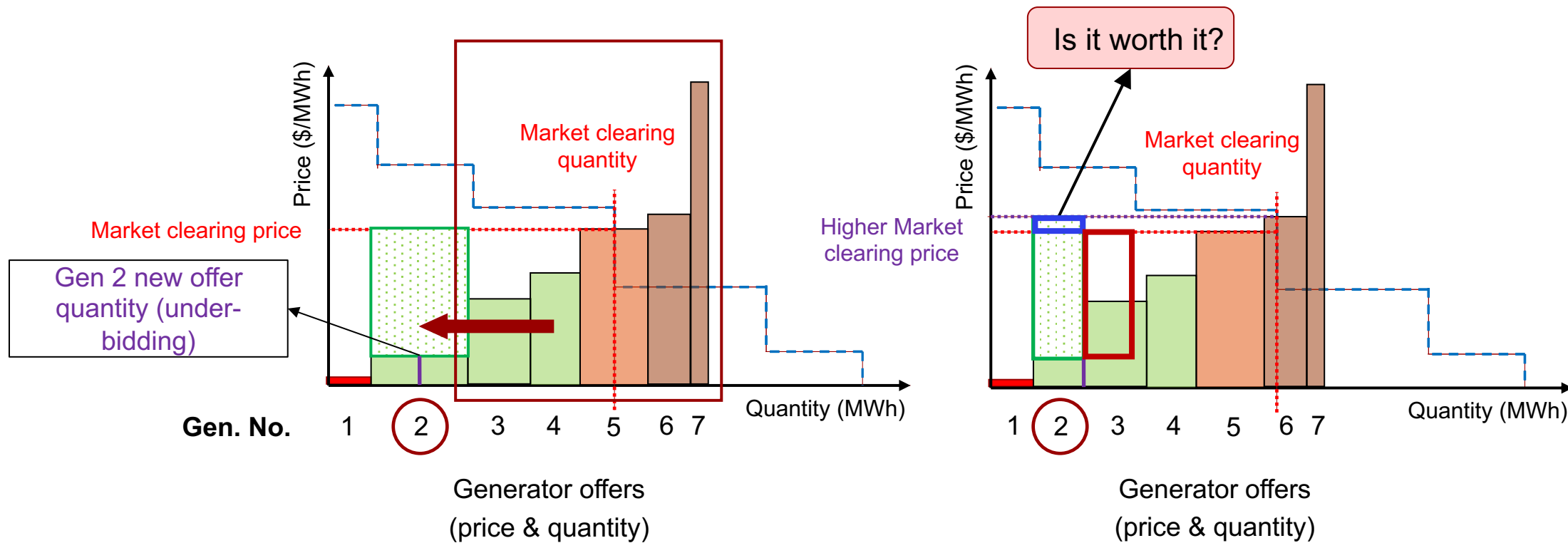
Strategic Players in the Market

Electricity market clearing with the merit-order

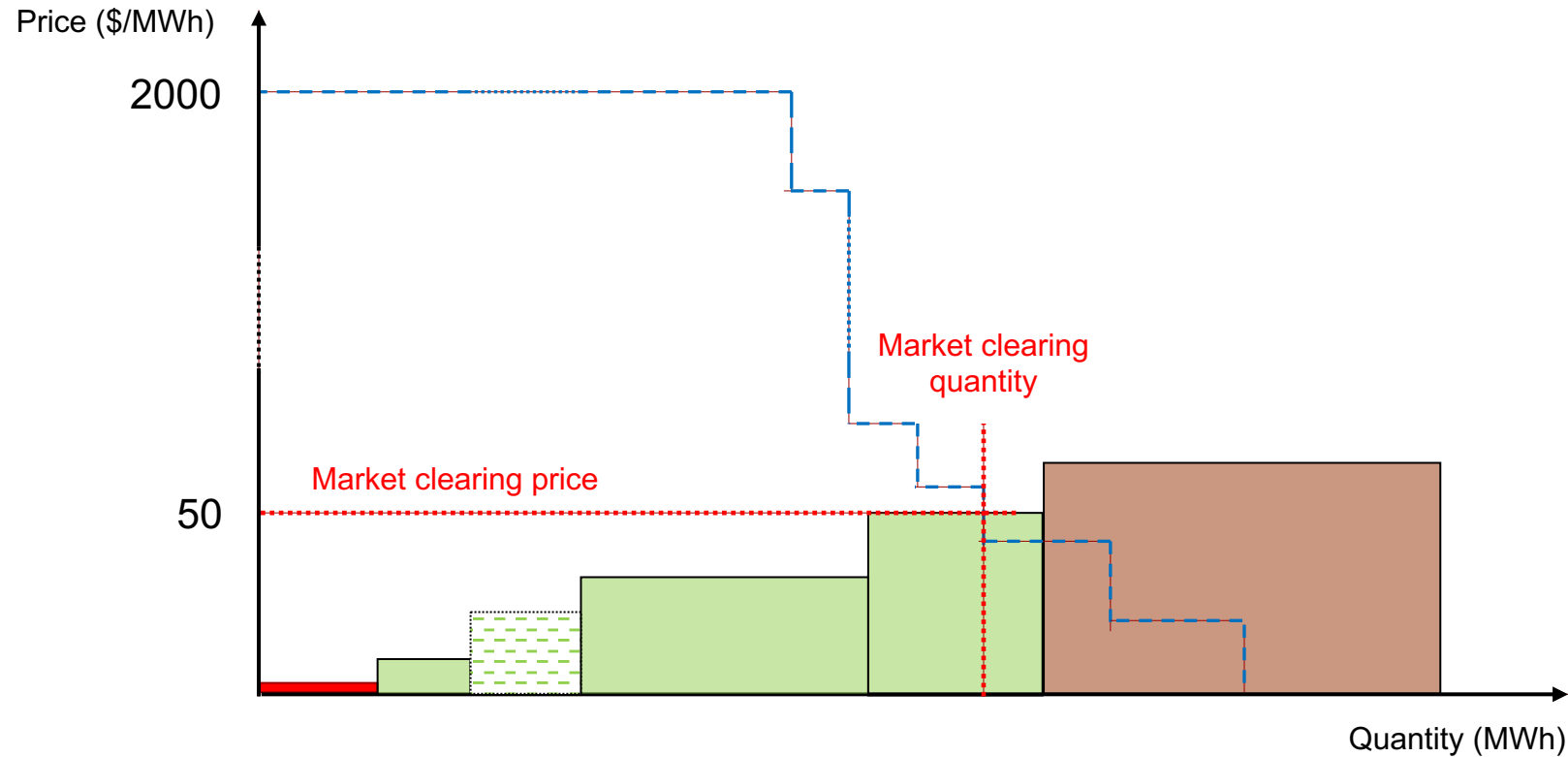


Strategic Players in the Market

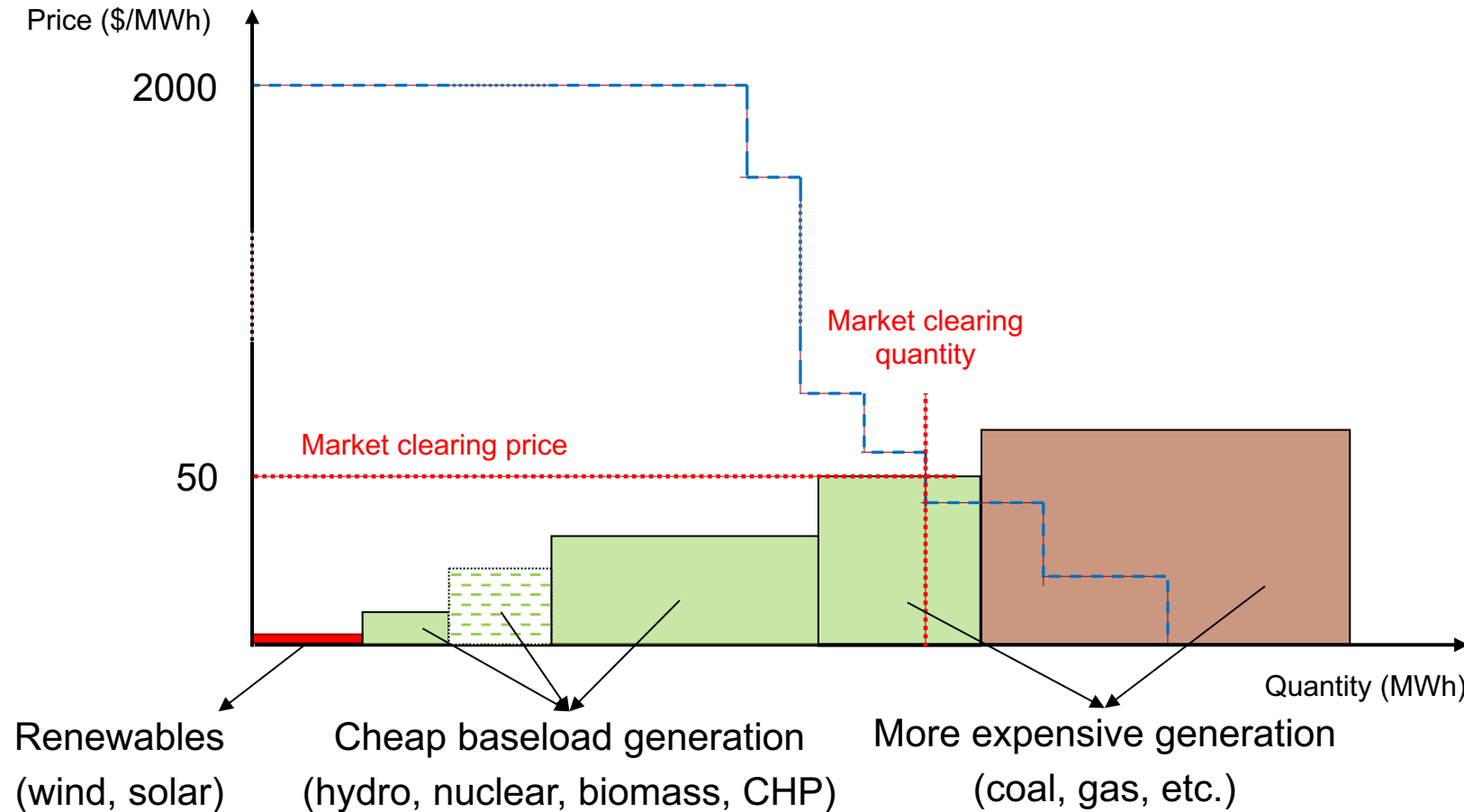
Electricity market clearing with the merit-order



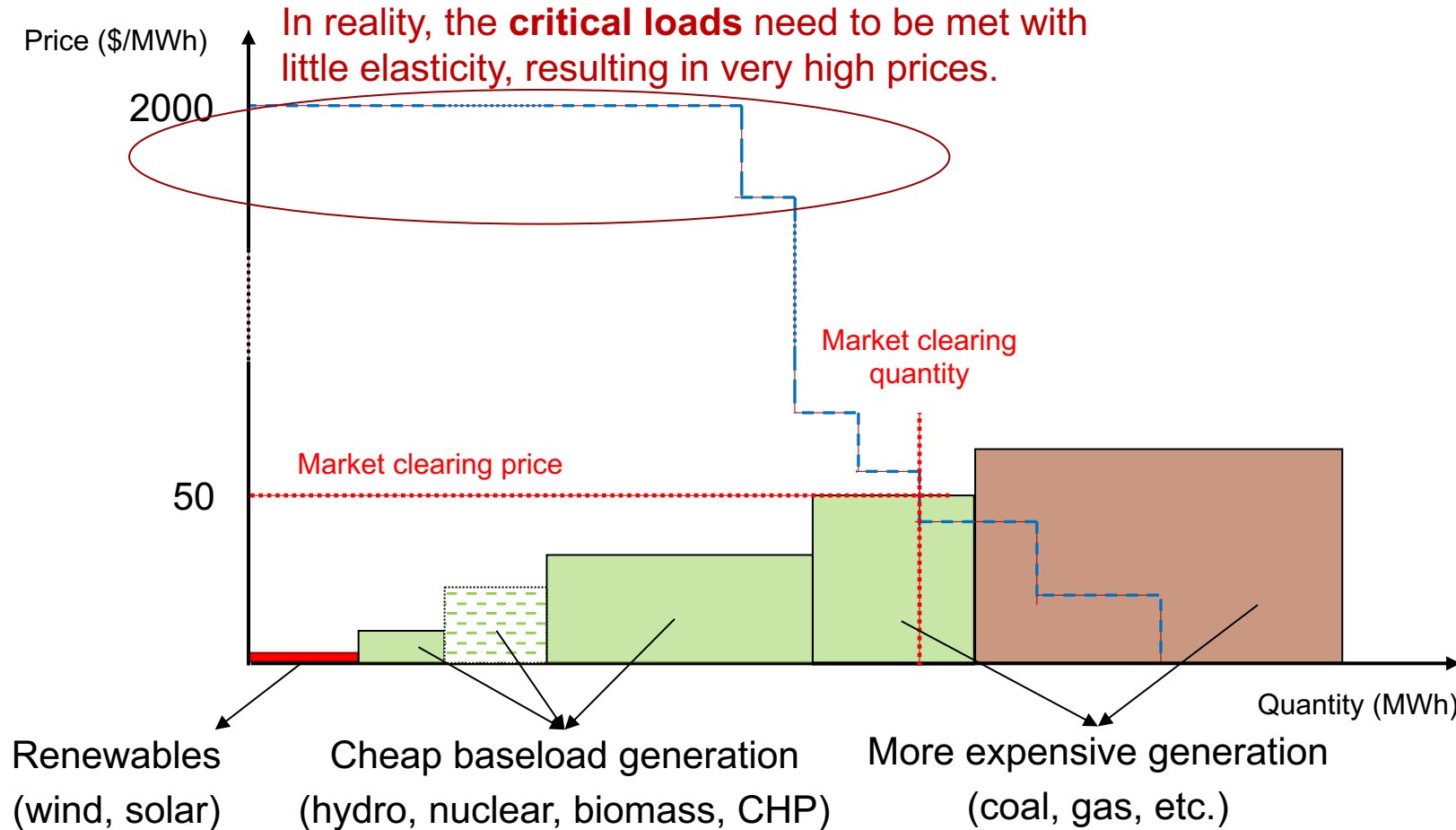
Strategic Players in the Market



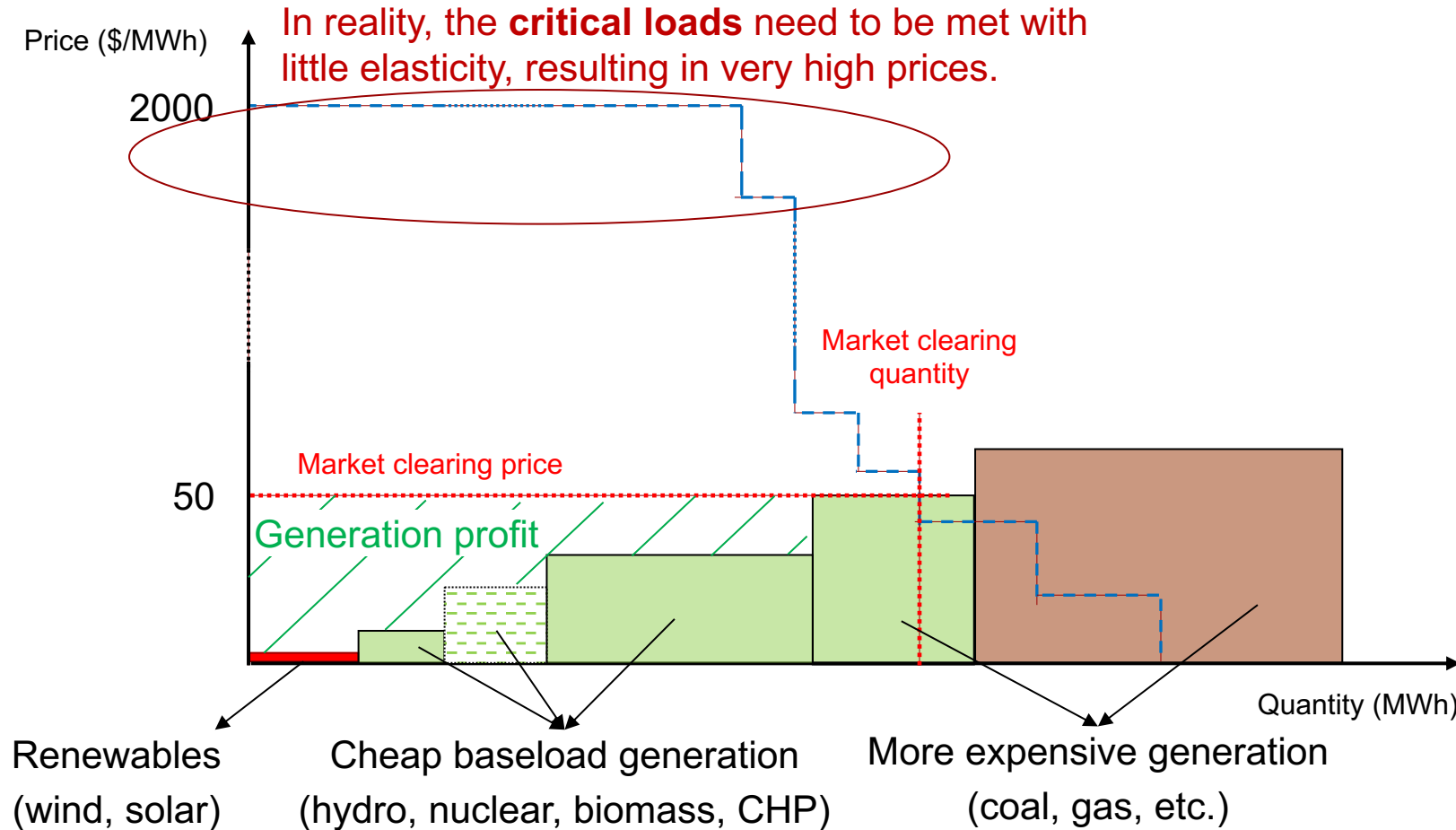
Strategic Players in the Market



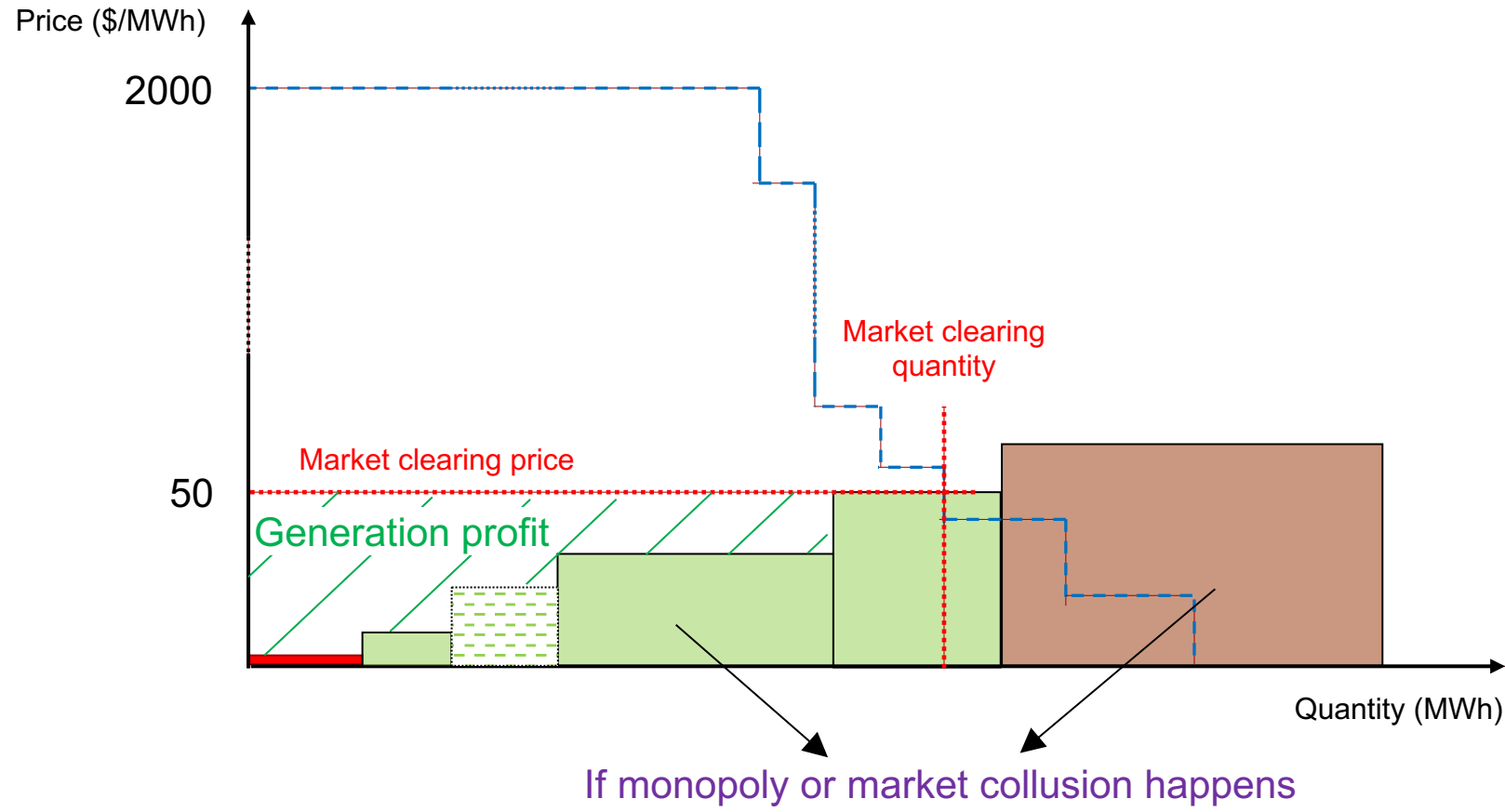
Strategic Players in the Market



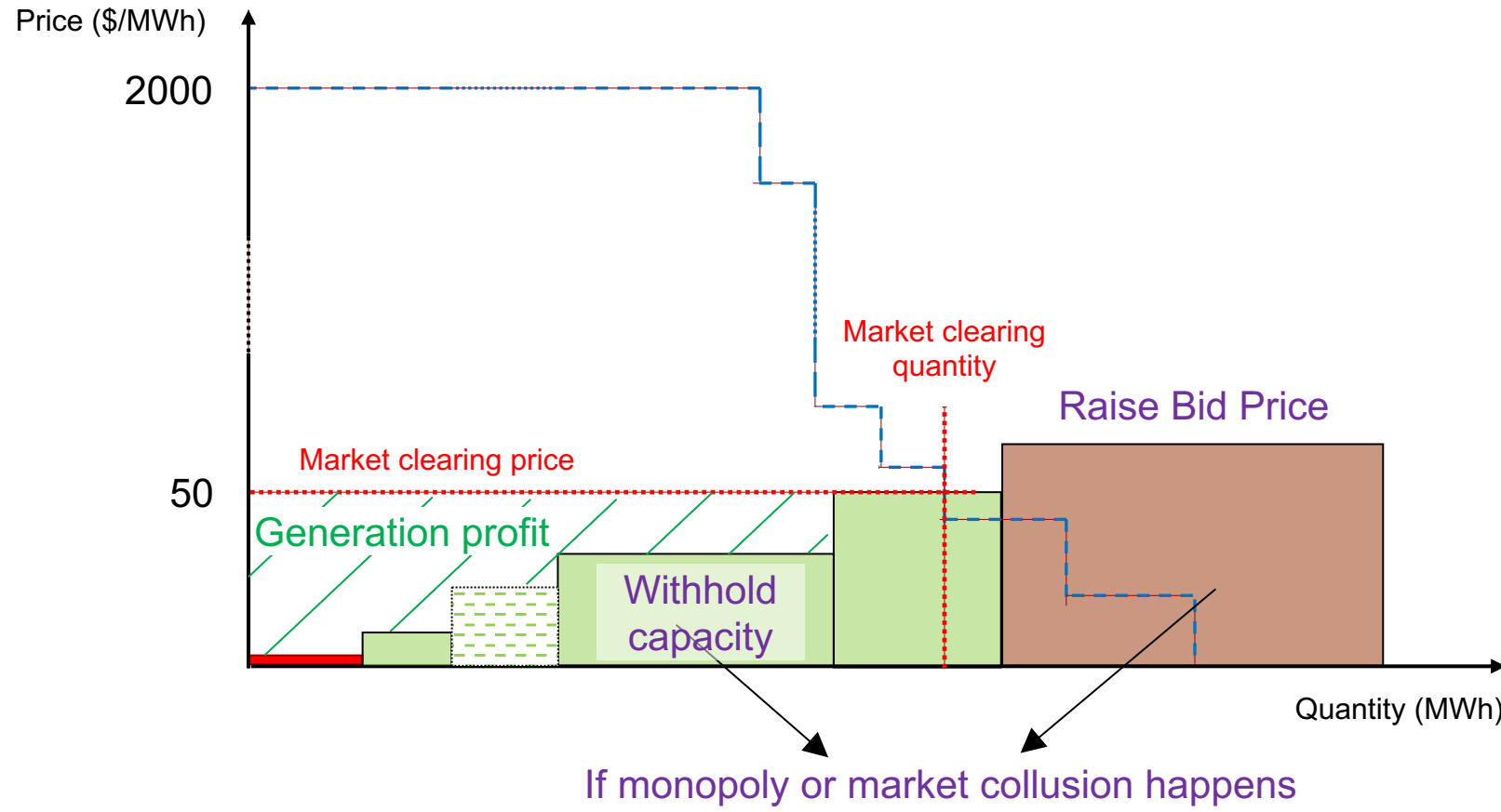
Strategic Players in the Market



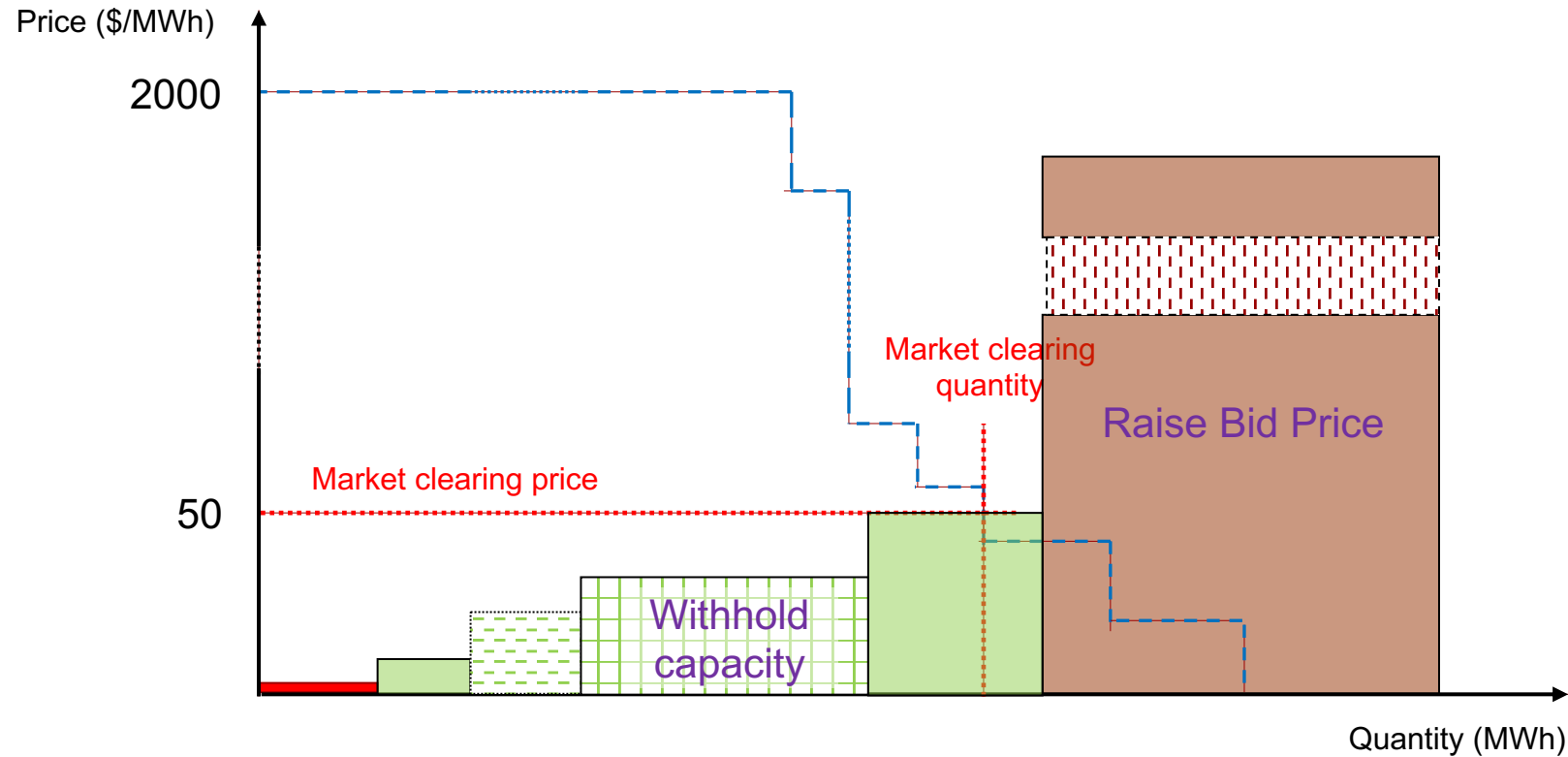
Strategic Players in the Market



Strategic Players in the Market

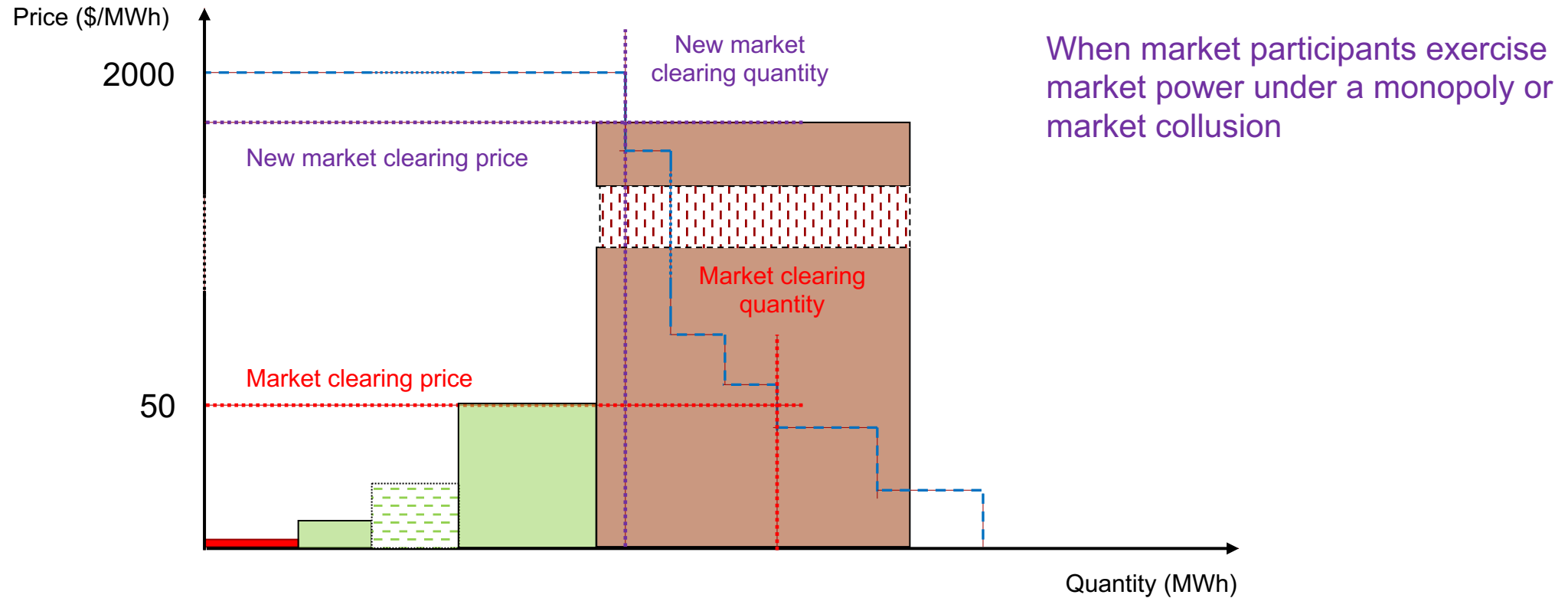


Strategic Players in the Market

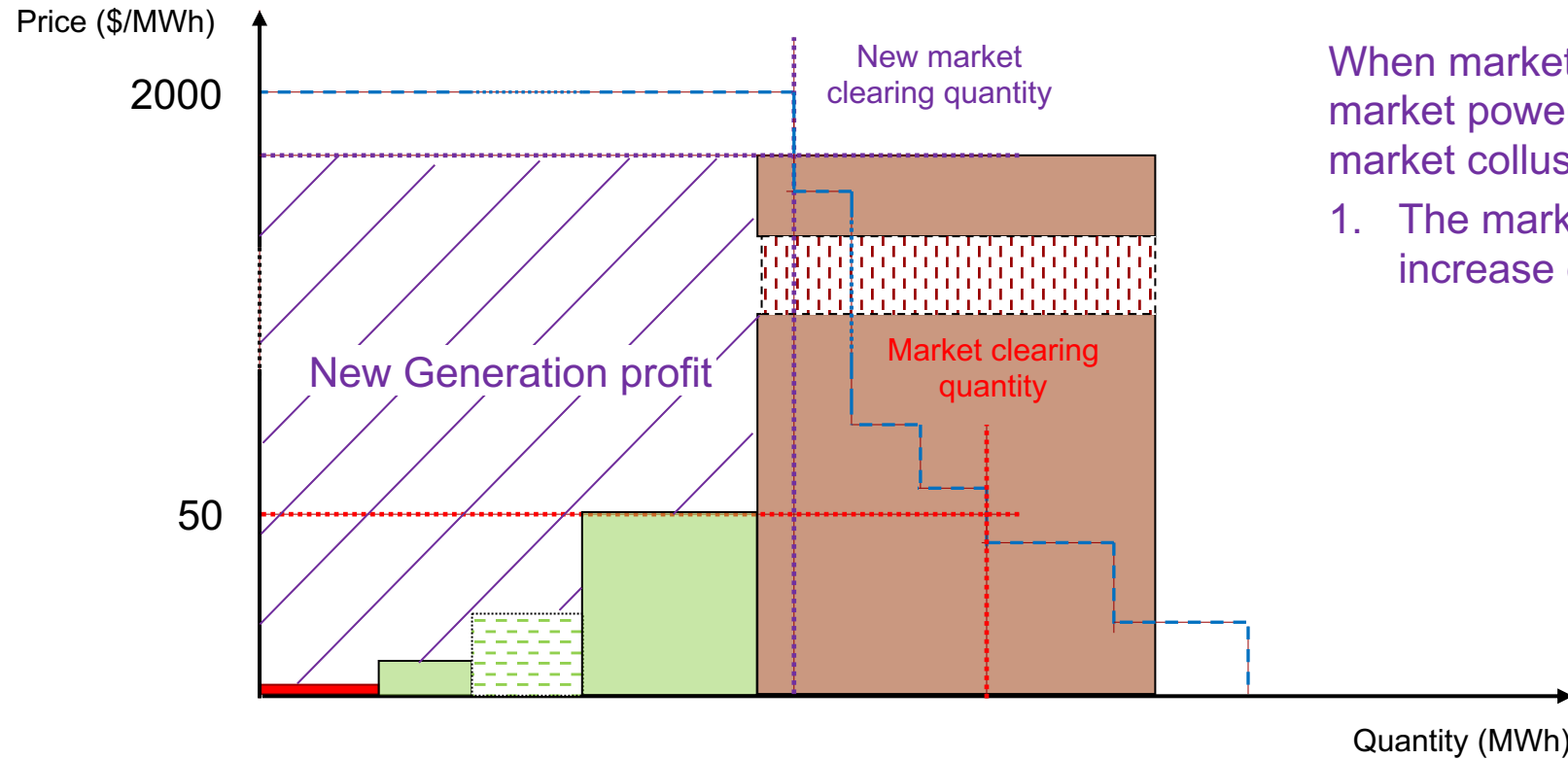


If monopoly or market collusion happens

Strategic Players in the Market



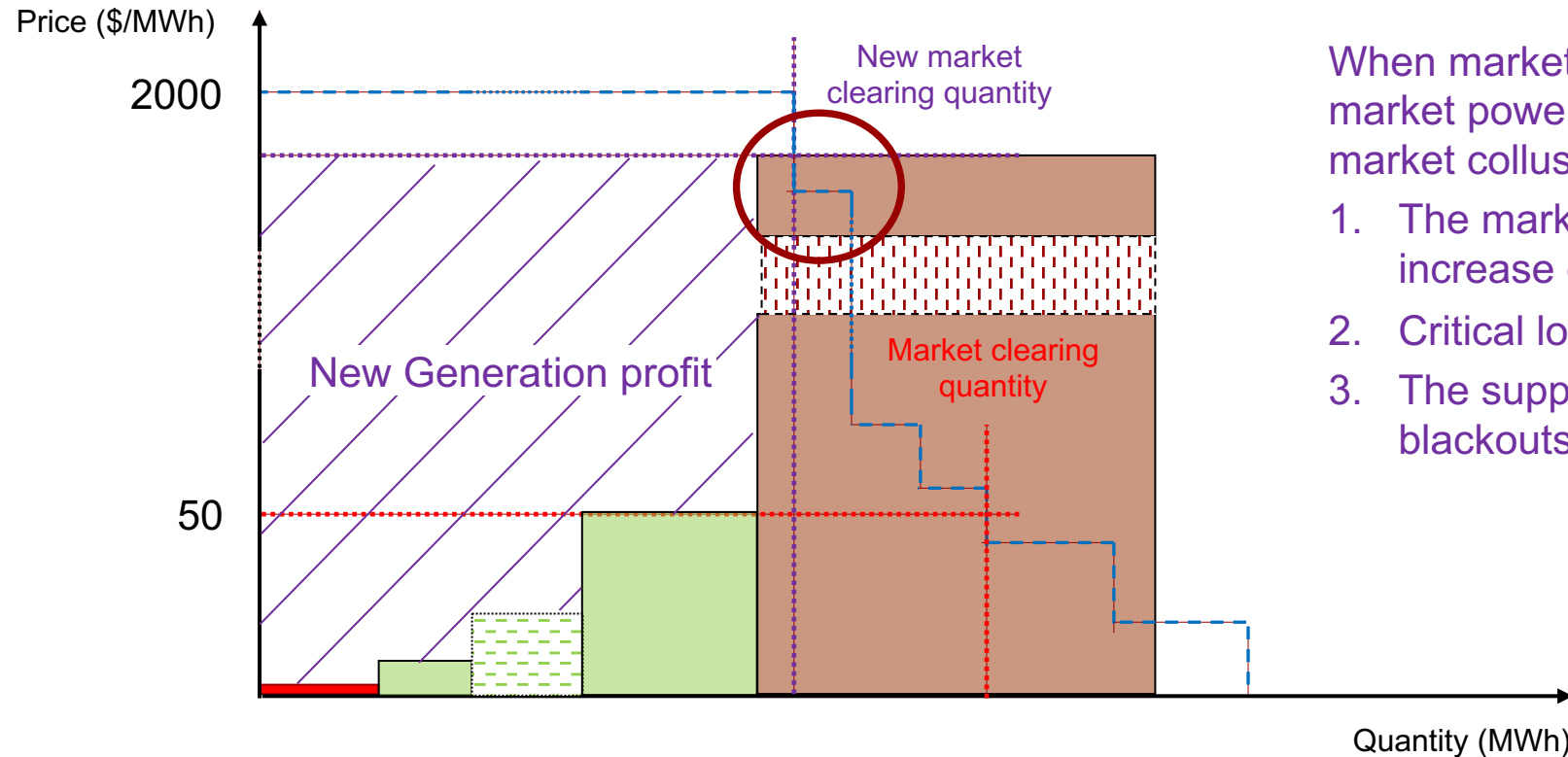
Strategic Players in the Market



When market participants exercise market power under a monopoly or market collusion,

1. The market clearing price may increase drastically.

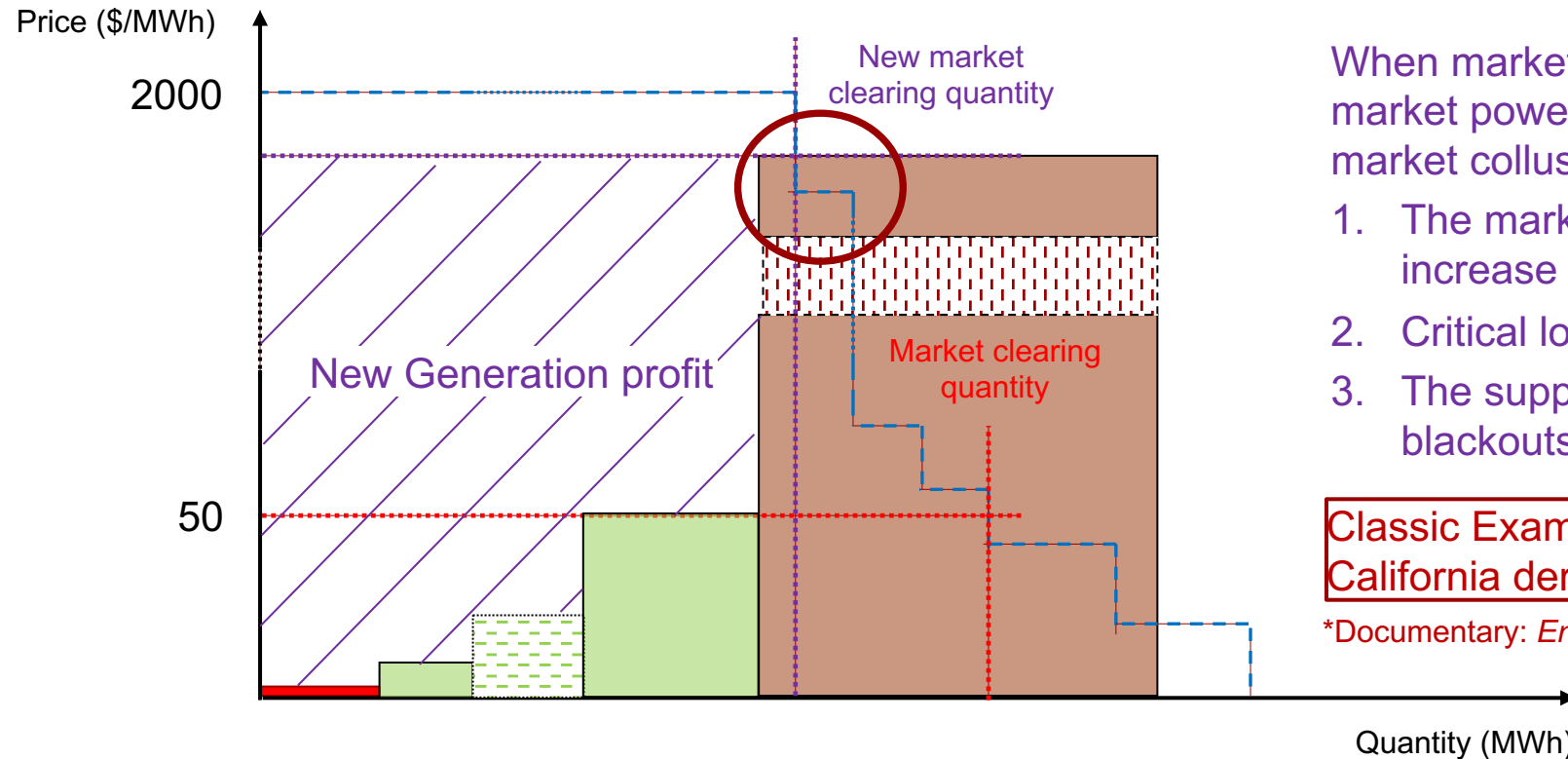
Strategic Players in the Market



When market participants exercise market power under a monopoly or market collusion,

1. The market clearing price may increase drastically.
2. Critical loads may not be met.
3. The supply shortage could lead to blackouts.

Strategic Players in the Market



When market participants exercise market power under a monopoly or market collusion,

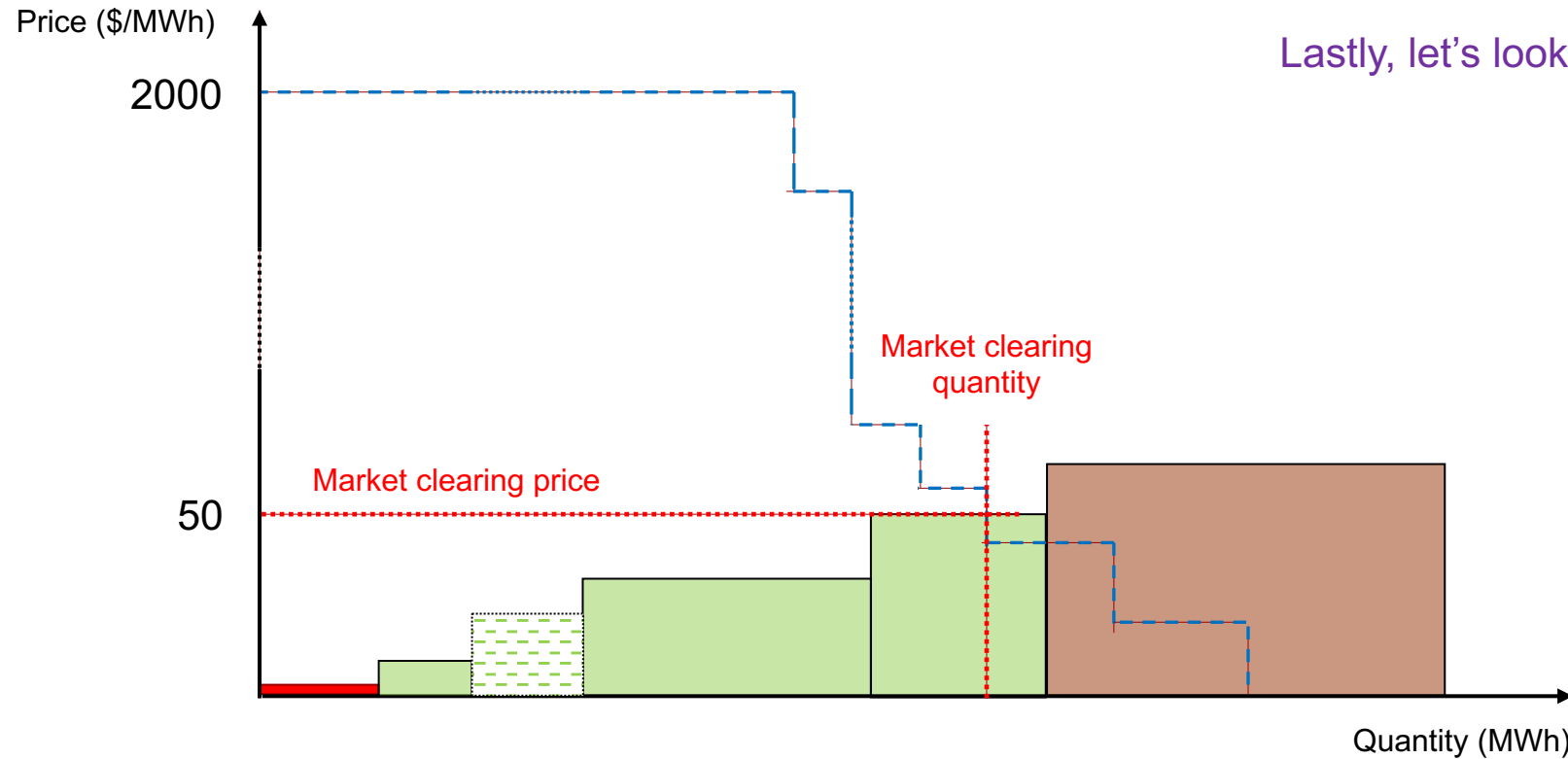
1. The market clearing price may increase drastically.
2. Critical loads may not be met.
3. The supply shortage could lead to blackouts.

Classic Example: **Enron*** manipulating the California deregulated market in 2000-2001

*Documentary: *Enron: The Smartest Guys in the Room*

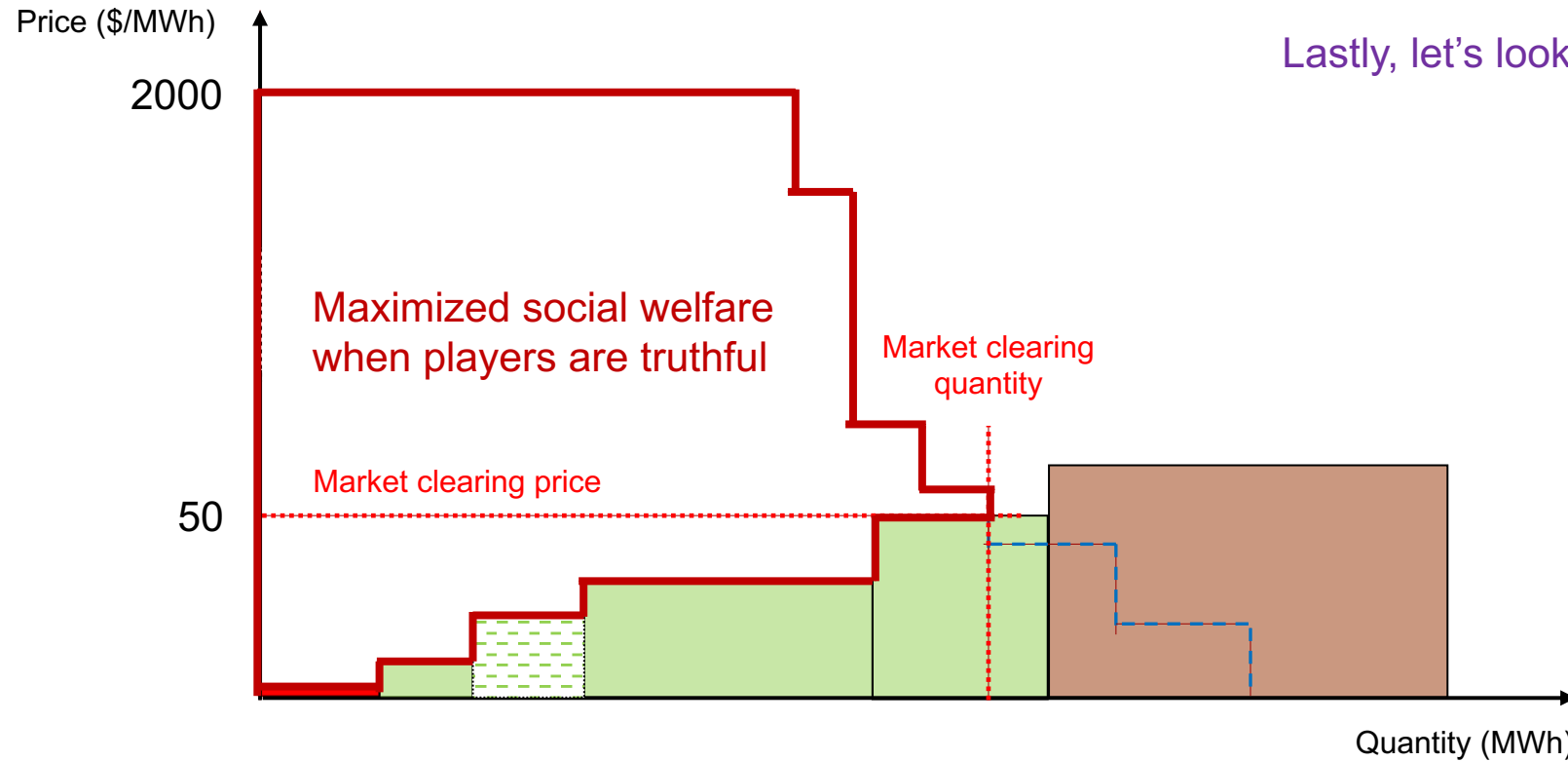
In the 2000-01 California electricity crisis, the wholesale price went up to \$1400/MWh. During one of the blackouts, the demand was only 28GW when the generating capacity was 45 GW.

Strategic Players in the Market



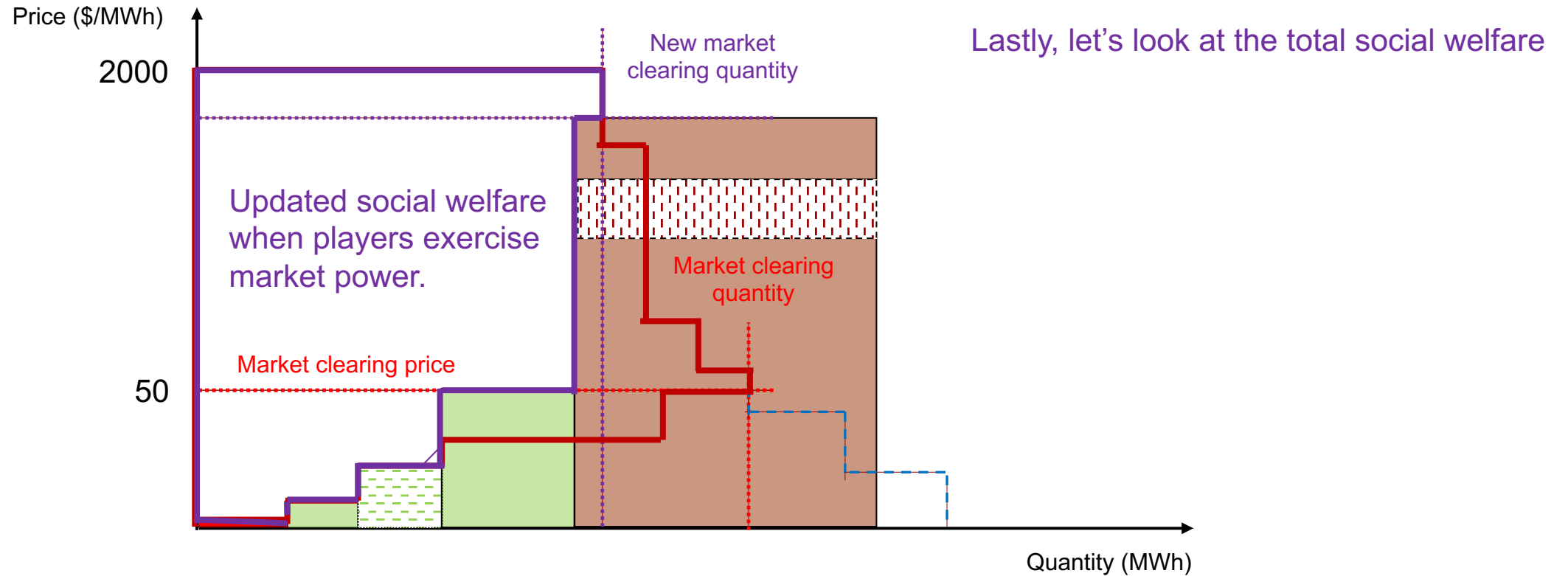
Lastly, let's look at the total social welfare

Strategic Players in the Market

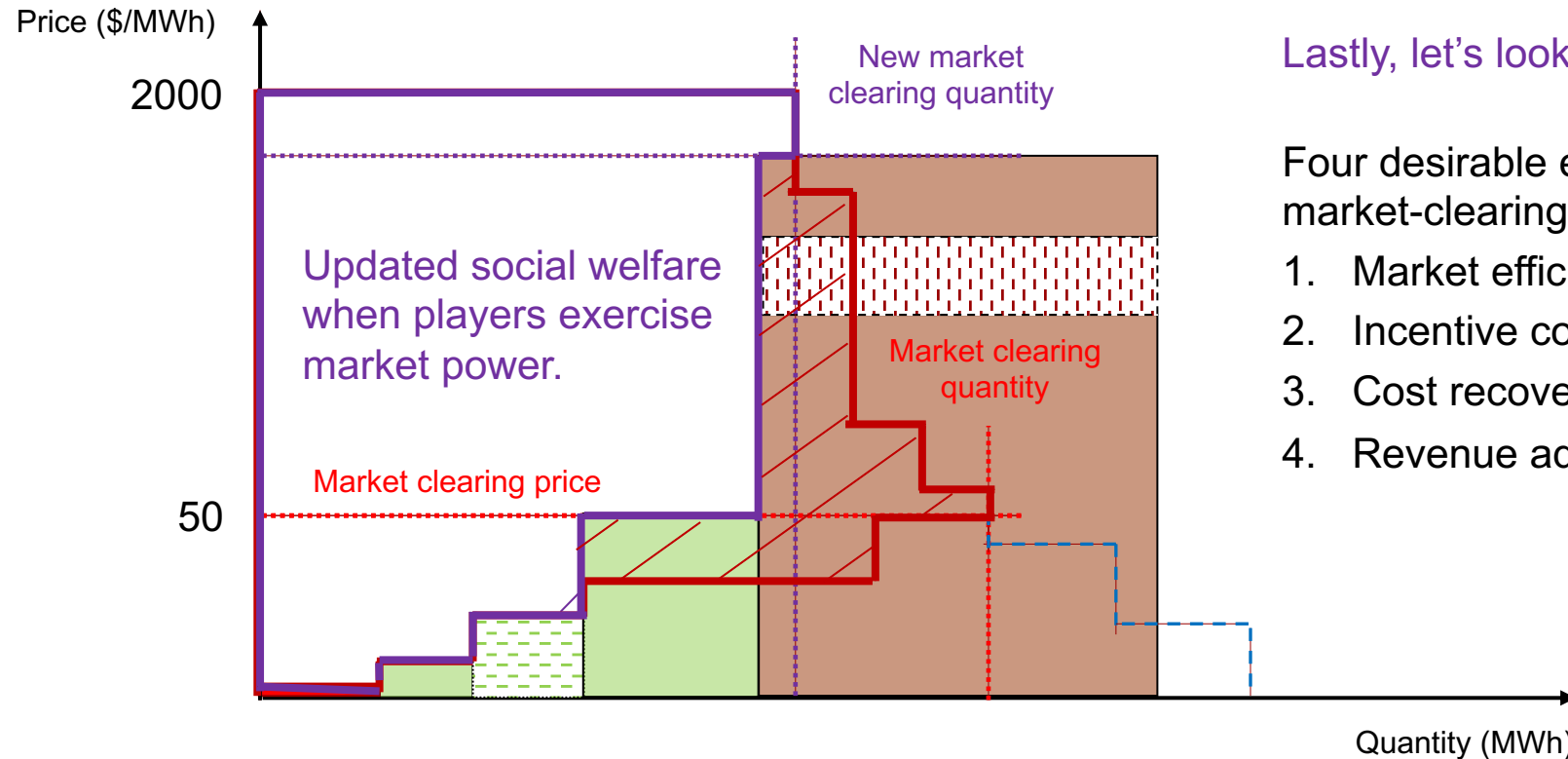


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Strategic Players in the Market



Strategic Players in the Market

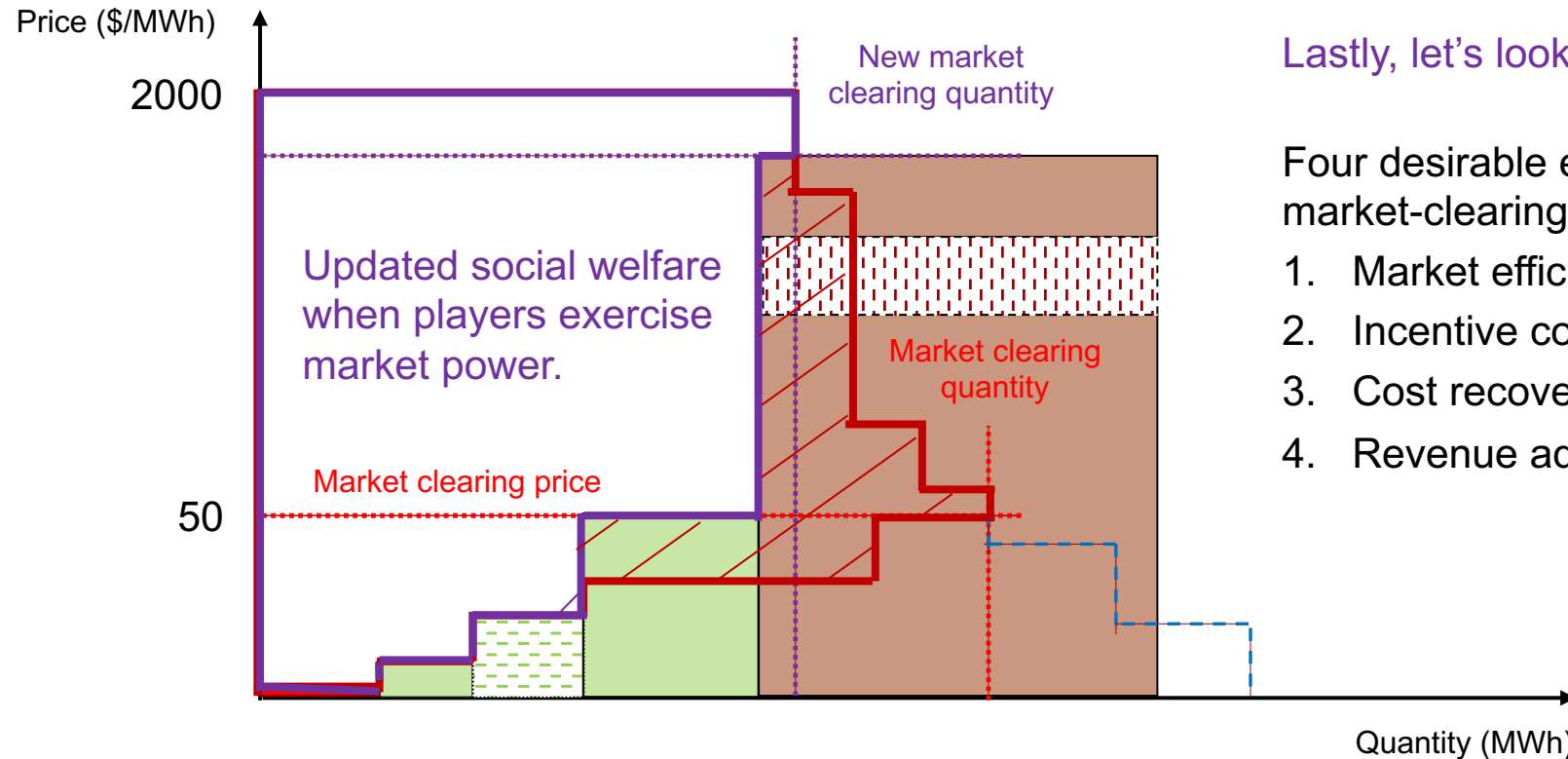


Lastly, let's look at the total social welfare

Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency (?)
2. Incentive compatibility (?)
3. Cost recovery / individual rationality 😊
4. Revenue adequacy (balanced budget) 😊

Strategic Players in the Market

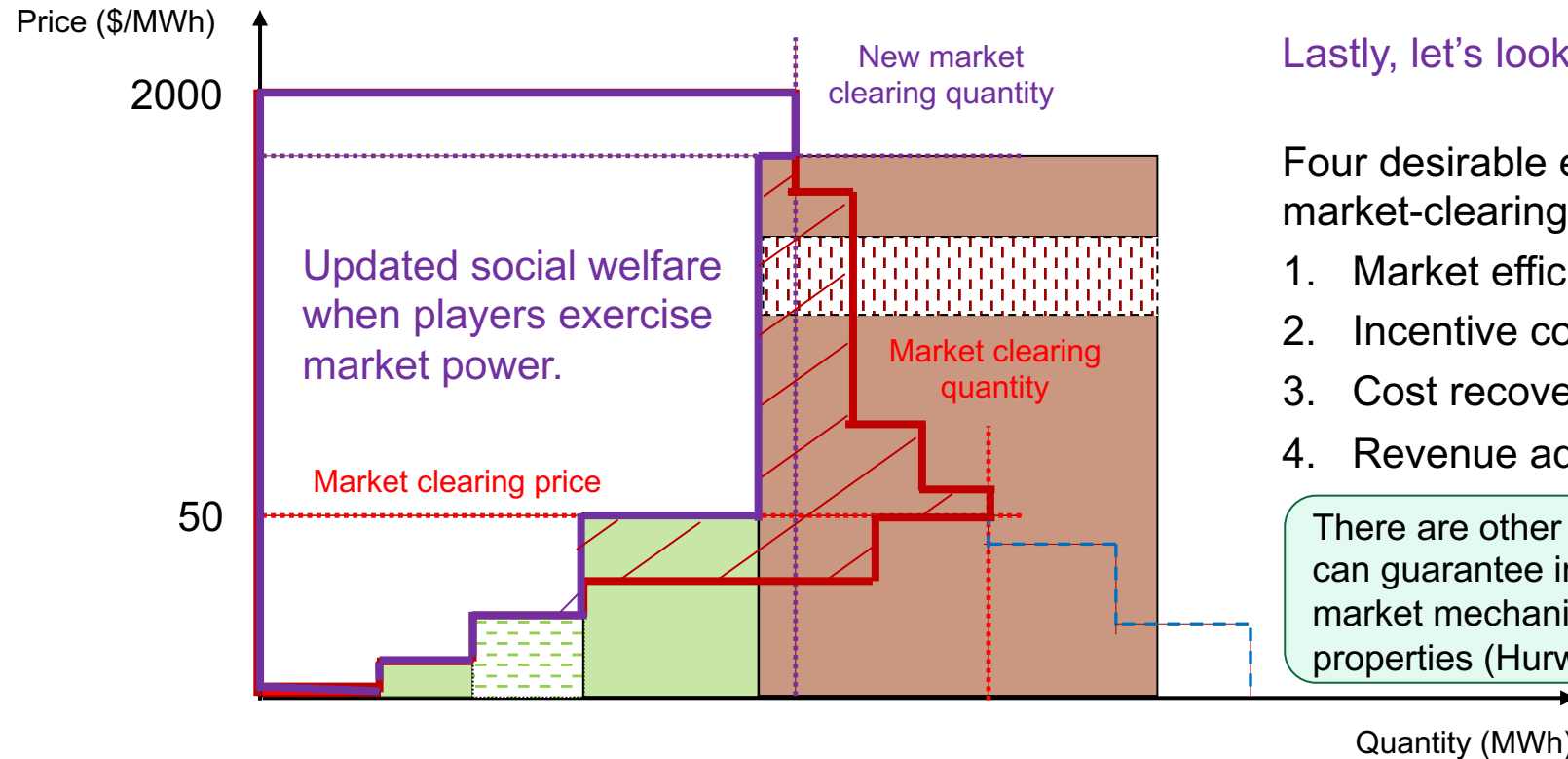


Lastly, let's look at the total social welfare

Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency ☹️
2. Incentive compatibility ☹️
3. Cost recovery / individual rationality 😊
4. Revenue adequacy (balanced budget) 😊

Strategic Players in the Market



Lastly, let's look at the total social welfare

Four desirable economic properties of market-clearing mechanisms:

1. Market efficiency 😞
2. Incentive compatibility 😞
3. Cost recovery / individual rationality 😊
4. Revenue adequacy (balanced budget) 😊

There are other market clearing mechanisms that can guarantee incentive compatibility, but **no** market mechanism can guarantee all four market properties (Hurwicz' "Impossibility Theorem").

Learning Objectives

In today's lecture, we will be discussing the **market properties** under **uniform pricing**, and potential price-maker strategies.

After this lecture, you should be able to

1. Explain the difference between a **price-maker** and a **price-taker**;
2. Name and provide the definitions of the four desirable **market properties**;
3. Name two types of **strategic actions** in the energy market from the producers' perspective, and explain the impact these actions have on the market clearing **price**, clearing **quantity**, the **payoffs** of all the market participants, and the **social welfare**;
4. Formulate the market clearing under uniform pricing both in an **optimization problem** and on a **merit-order curve**, and match each parameter and variable in the optimization problem to the corresponding graphical representation in the merit-order curve.

> Now you can do Assignment 2 Step 3 (a) and (b).

Thanks for your attention!

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March, 2022

Technical University of Denmark
Department of Wind and Energy Systems