Indian Institute of Technology Kanpur (IITK) and Indian Energy Exchange (IEX) are delighted to announce

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Bidding Strategy in Power Markets

By

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Present and Future Power Systems

Present Power System
- Heavily Relying on Fossil Fuels
- Generation follows load
- Limited ICT use
- Limited Competition

Future Power System
- More use of RES, clean coal, nuclear power
- Load follows Generation
- More ICT & Smart meter use
- More competition

More Gaming

Game Theory is a discipline that is used to analyze the problems of conflicts among interacting decisions.

* Cooperative   * Non-cooperative

- zero sum game (*gain of one player is equal to the loss of other player*)
- non-zero sum game (*gain of one player do not equal to the loss of other player*). First formulated by Nash.

- Non cooperative games can be described using two formats
  - Extensive form: extensive form games model multi-agent sequential decision making
  - Normal or strategic forms: strategic form games are used to model one-shot games in which each player chooses his action once and for all simultaneously.
    - *It deals with a set of players, a set of choices or strategies available with the players and a set of payoff corresponding to these strategies*).

Rule of game, strategies available to players and payoff are common knowledge.

- Each player must act rationally to maximize its profits

Prisoners' Dilemma

- Two individuals are arrested under suspicion of a serious crime (murder or theft). Each is known to be guilty of a minor crime, but it is not possible to convict either of the serious crime unless one or both of them confesses.
- The prisoners are separated and asked for confess.
- Both announce to a referee "Give me $1000" or "Give the other player $ 3000". Money under either strategies comes from a third party. They can either cooperate or defect & implicate other player.

- Cooperate strategy for each player is to give $3000

Payoff ($)		Player B		
		Cooperate	Defect	
Player A	Cooperate	3000	0	A's payoff
		3000	4000	B's payoff
	Defect	4000	1000	A's payoff
		0	1000	B's payoff

- Nash equilibrium in this game is defect strategies.
- At Nash equilibrium, a players payoff decreases if it changes it strategy, assuming the strategies of other players are same.

Example-1

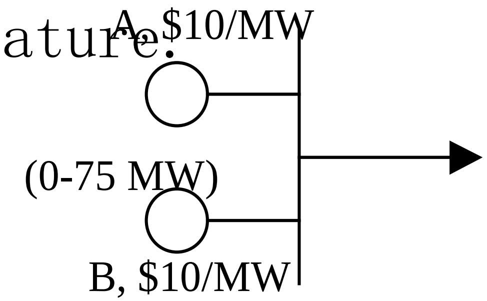
- Let genenerator-1 has capacity of 100 MW with production cost $75/MW per unit time. Demand is 100 MW. Bid of other gen at the same bus is

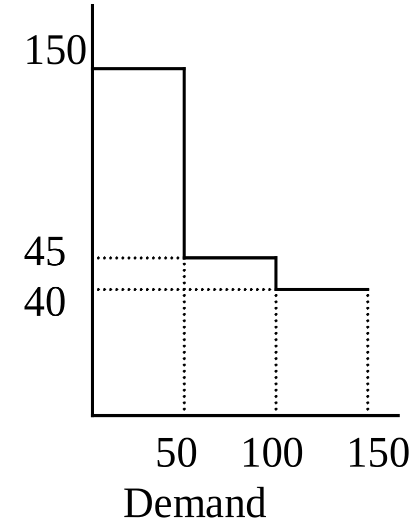
50 MW	101 $/MW
50 MW	121 $/MW

- *What should be bid of gen-1?*
- Option-1: bid at 100 $/MW
  - win all demand of 100 MW. The profit will be 100(100-75)= 2500
- Option-2: bid at 120 $MW
  - win 50 MW capacity. The profit will be 50(120-75)= 2250
- This shows the option-1 is preferred.
- If second block of other gen. is 131 $/MW. Profit at bid price of 130 will be 50(130-75) = 2750.
  - Now this is preferred.

Example-2:

- Two generators A and B have same production cost of \$10/MW and same ratings of 75 MW. They have to supply to a load of following nature:





Let both bid in two levels: High (75 MW) and low (20 MW). The output decision can be

Output (MW)		Generator B High	Generator B Low	
Gen. A	High	75	75	A's output
		75	20	B's output
	Low	20	20	A's output
		75	20	B's output

- *Price corresponding to the output decisions*

Price ($/MWh)		Generator B High	Generator B Low
Gen. A	High	40	45
	Low	45	150

- *Profits*

Profit ($)		Generator B High	Generator B Low	
Gen. A	High	2250	2625	A's profit
		2250	700	B's profit
	Low	700	2800	A's profit
		2625	2800	B's profit

Bidding Strategy in Electricity Markets

- **Theoretically, in perfect electricity markets, suppliers should bid at or very close to their marginal cost to maximize profit.**
- **However, the electricity market is not perfectly competitive due to limited number of producers, therefore, power suppliers may seek to benefit by bidding a price higher than the marginal production cost.**
- **When a supplier bids other than the marginal cost, to take advantages of imperfect market to increase their profit, this behavior is called strategic bidding.**
- **The bidding strategy decision of an individual supplier can be affected by demand variation, generator cost characteristic, rivals bidding behavior, operating and regulatory constraints.**
- **Each supplier developed bidding strategy to maximize their profit, considering own costs and constraints, rivals' bidding behavior and market rules.**

Bidding in Constrained Network

- **Transmission constraints restricts the flow of power from low cost node to high value nodes.**
- **Since transmission network capacity is limited, it may happen necessary to select expensive bid to avoid transmission overloading. Therefore, constraints on the system will cause different prices at different nodes.**
- **Revenue collected from the consumer will be more than the money paid to the generators in uniform market clearing price system.**
- **The market based congestion management methods can be categorized as:**
  - **Locational marginal price**
  - **Zonal price**
  - **Market split**
  - **Counter flow re-dispatch**

Bidding Strategies Formulations

Bidding problem formulation depends upon the market model, type of bidding protocol, auction mechanism and estimation technique of rivals' bidding behavior.

1. **Deterministic formulation**
   - **Uncertainty are not included**
   - **No temporalities**
   - **All rivals are clubbed together**
2. **Stochastic formulation**
   - **Uncertainty of bid price of rivals**
   - **Uncertainty of demand**
   - **Temporalities are considered**
   - **Rivals' are not clubbed**

Solution approaches

1. **Conventional methods**
2. **Heuristic approaches**

Bidding Strategies

- Deterministic formulation
  - Assumptions
    - uncertainty are not included
    - No temporalities
    - All rivals are clubbed together
  - Rival:
    - Block: ϕ_1, ϕ_2, ……. . . , ϕ_J MW
    - Price : ρ_1, ρ_2, …. . . , ρ_J \$/MW ($\rho_{j+1} > \rho_j$; $\forall j$)
  - Seller:
    - Block: H_1, H_2, ……. . . , H_I MW
    - Cost : c_1, c_2, …. . . , c_I \$/MW ($c_{i+1} > c_i$; $\forall i$)
    - Bids : p_1, p_2, …. . . , p_I \$/MW
  - Seller will maximize it profit

Bidding Strategies

- Seller will maximize

$$\sum_{i\in I} H_i(p_i - c_i)v_i$$

- v_i is 1 if dispatched, otherwise zero.

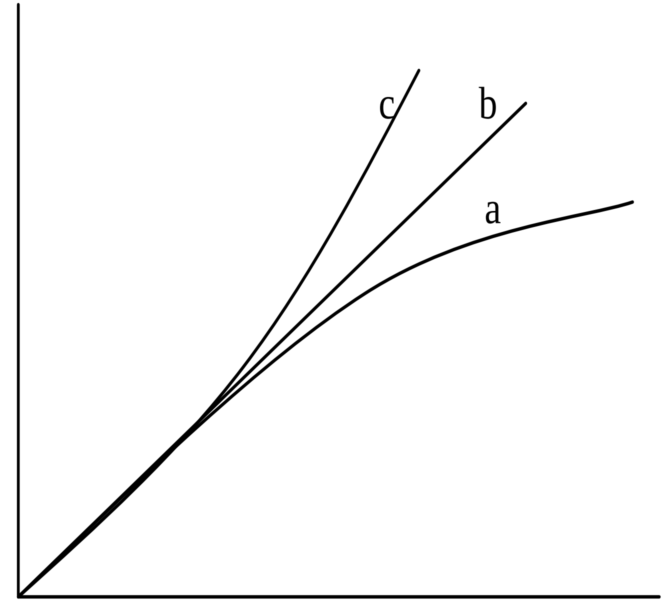
$$v_i = \begin{cases} 1 & iff \left\{ \begin{aligned} &(p_i > \rho_j)\text{and}(p_i < \rho_{j+1}), and \\ &\sum_{k=1}^{j}\phi_k + \sum_{k'=1}^{i-1} H_{k'} \le D \end{aligned} \right\} \\ 0 & \text{otherwise} \end{cases}$$

- Seller maximize

$$\sum_{i\in I} H_i \Omega_i(z_i)v_i$$

- where Ω_i is preference function and $z_i = p_i - c_i$

- Preference function
  - it depends on the operational and economic reasons
  - $y = x^n$
  - n=1 ---> Fig b, n> 1 ---> fig c and n <1 ---. Fig a



  - Fig c: greater desire to sell even at low gain
  - Fig a: greater desire to sell even at high gain
  - Fig b: constant sell
- Uncertainty and Temporality
  - uncertainty of bid price of rivals
  - uncertainty of demand
  - $G_i(p_i)$ is a distribution function which denotes probability that block i will be sold if it was offered at price p_i

$$\sum_{i \in I} H_i \Omega_i^i (z_i) G_i (p_i)$$

- supplier must forecast the rivals bid price on previous data.
- Temporality is due to consumer response with price change.

Example: Supplier has two unit block as following cost

$$H_1 = 400\ \text{MW} \quad C_1 = \$50/\text{MWh}$$
$$H_2 = 200\ \text{MW} \quad C_2 = \$65/\text{MWh}$$

Let preference function be linear.

Rivals bids, If know

Block : 400, 400, 200, 200 MW

Price : 56, 66, 71, 76 $/MWh

Demand is 1000 MW

Objective Function

$$400(p_1 - 50)v_1 + 200(p_2 - 50)v_2$$

$$v_i = \begin{cases} 1 & iff \left\{ \begin{aligned} &(p_i > \rho_j)\text{and}(p_i < \rho_{j+1}), and \\ &\sum_{k=1}^{j} \phi_k + \sum_{k'=1}^{i-1} H_{k'} \le D \end{aligned} \right\} \\ 0 & \text{otherwise} \end{cases}$$

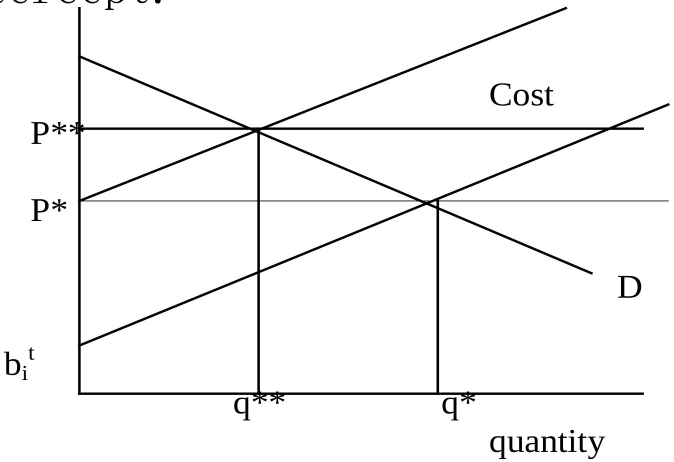
Options are

- **P1= 55, P2= 65**
- **P1= 65, P2= 65**
- **P1=70**

Imperfect competition and strategic Bidding

- Strategic bidding by a generator is simply choosing a bid (a strategy) that maximizes its own profits.
- Under many circumstances, a producers best strategy will bid somewhat different than the marginal cost curve. Generator will make money at the expense of the consumers. This is imperfect competition.
- Considering the linear bid, the choice of producer to maximize the profit by choosing the slope and the intercept.
- Producer-I's profit

$$\Pi = \frac{1}{2}\left[(p^{**} - b_i^t) + (p^{**} - (b_i^t + m_i^t q_i^{**}))\right] q_i^{**}$$



$$p_{s1} = 10 + 0.35 q_1 \qquad p_{s2} = 10 + 0.45 q_2$$

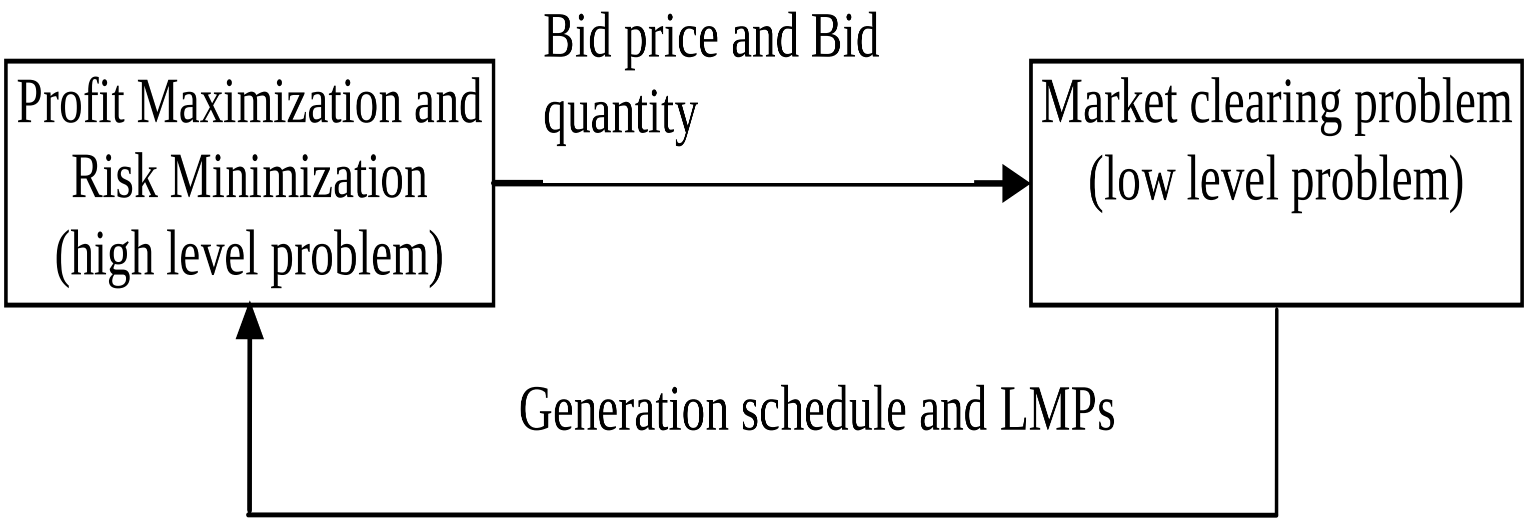
$$p_{d1} = 100 - 0.52 d_1 \qquad p_{d2} = 100 - 0.65 d_2$$

- Example: Find the market clearing price. Given that

  Hint: $q_1+q_2=d_1+d_2$.

- Sol: P*= 46.4, q_1=104, q_2= 81, d_2=82, d_1=103

Block diagram of the Bi-Level optimization process



Approach for Estimation of Rivals' Strategy

- **For each rival generator, the possible strategies and their associated probabilities estimated by the generator, for which bidding is to be framed, can be denoted by matrices**

$$\begin{pmatrix} S_{j11} & \cdot & \cdot & \cdot & S_{j1G_j} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ S_{jk_j1} & \cdot & \cdot & \cdot & S_{jk_jG_j} \end{pmatrix} \quad \textbf{and} \quad \begin{pmatrix} pr_{j11} & \cdot & \cdot & \cdot & pr_{j1G_j} \\ \cdot & \cdot & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ pr_{jk_j1} & \cdot & \cdot & \cdot & pr_{jk_jG_j} \end{pmatrix}$$

where,

***j={1, 2, . . . i-1, i+1,…N }* is the set of the generators excluding the *i*^th^ generator.**

- **For each opponent Genco *j* there is N_j number of possible strategy combinations, defined as** $\boldsymbol{\Phi}_j = \{\boldsymbol{\Phi}_{j1}, \boldsymbol{\Phi}_{j2}, \ldots \boldsymbol{\Phi}_{jnj}, \ldots, \boldsymbol{\Phi}_{jNj}\}$ **and their probabilities are represented as** $\boldsymbol{\eta}_j = \{\eta_{j1}, \eta_{j2}, \ldots, \eta_{jnj}, \ldots, \eta_{jNj}\}$

$$N_j = K_j \times G_j$$

K_j is the maximum number of blocks to bid and G_j is the maximum number of strategies for j^{th} Genco.

Contd…

e) Divide the range of the objective function $F_2, \ldots\ldots, F_p$ **into** $q_2, \ldots\ldots\ldots, q_p$ **equal intervals, respectively. Considering maximum and minimum values of the** $q_2+1, \ldots\ldots\ldots, q_p+1$ **range,** $F_2, \ldots\ldots, F_p$ **equidistant grid points are produced for , respectively.**

f) Solve $(q_2+1) \times \ldots\ldots\ldots\ldots \times (q_p+1)$ **optimization sub problems considering the constraints. Sub problem (i,j) has the following form,**

$$Max \quad F_1(x)$$

Subject to,

$$F_2(x) \le e_{2i}, F_3(x) \le e_{3i}, \ldots\ldots\ldots F_p(x) \le e_{pi}$$

$$e_{ki} = F_k^{\max} - \left[\frac{F_k^{\max} - F_k^{\min}}{q_k}\right] * i, \quad i = 0,1,\ldots\ldots q_k, k = 2,\ldots\ldots p$$

where, max and min represents the maximum and minimum values of the individual function, obtained from the pay off table. By solving all the optimization sub problems, $(q_2+1) \times \ldots\ldots\ldots\ldots \times (q_p+1)$ **pareto optimal solutions are obtained.**

Estimation of Rivals' Bidding Strategy

- **The normal probability density function (pdf) used to represent the rivals' bidding prices distribution**

$$pdf(\rho_n) = \frac{1}{\sqrt{2\pi\sigma_n}} \exp\left(-\frac{(\rho_n - \mu_n)^2}{2(\sigma_n)^2} \right)$$

- **Monte Carlo method : It is used to estimate the rivals' bidding price as:**

  - **Generate large number of random samples of bid prices of all the rivals according to their pdfs.**
  - **Obtain large trial outcomes by solving the optimization problem with sample values of bid prices of all the rivals.**
  - **Calculate the expectation value taking average of all the trial outcomes.**

Electric Energy Trading

- An electricity market should be supported and implemented by proper trading tool by which objective of deregulation can be obtained.
- Trading is an activity in which transactions would take place directly between two participants (i.e. *over-the-counter* (OTC)) or indirectly through an organized market place or Echange.
  - *Physical Trading*, where supply would be balanced against demand and price would be either determined in advance of trading (*ex-ante*) or after trading (*ex-post*).
  - *Financial Trading:* Financial contracts would take place between trades as agreement that would give certainty to traders.

- Electricity trading through exchange started for first

Electric Energy Trading

- Trading Instruments
  - Future
  - Forward
  - Option
  - Swap
- In spot market, electricity is traded for actual physical delivery to transmission grid.
- Future and forward contract would include an obligation to buy or sell a specific quantity at a certain future time for a certain price.
- Option contract include a right (not obligation) to buy or sell.
- Swaps are the other type of derivative that market entities could use for hedging the risk.

Future, Option and Forward Contracts

- Future Contract
  - A future contract is a standardized one to deliver or receive a certain quantity of a commodity at some stated time in the future.
  - Price, quantity, grade, location and time of future delivery are all stated in the contract. Note, however, that the only point of negotiation is the price. All other terms and conditions are pre-specified, thereby making it a standardized contract.
  - A future contract is therefore not specifically drawn to tailor the needs of any particular set of trader & this in effect maximizes transferability and hence liquidity.
  - That is, other parties, including speculators, can purchase and resell the contract in the secondary

- Future contracts relate to a specific month, several of which are traded at any one time. When the actual month of delivery arrives, all outstanding contracts must be settled by delivery of the commodity or by an offsetting contract.
- The main justification of the Future contract is that it permits specialization between two elements of the economic process—the function of holding commodities (or other assets) and the function of bearing the risk of price changes
- The seller of a Future contract on a commodity does not normally intend to deliver the actual commodity nor does the buyer intend to accept delivery; each will, at some time prior to the date of delivery specified in the contract, cancel out obligation by an offsetting purchase or sale.
- In fact, historically, less than one or two percent of

- The future and spot markets tend to parallel one another and to converge as the delivery date approaches.
- The relationship between spot and future market prices is such that at any point in time the future price and spot price should only differ due to the cost-of-carry.
- The cost-of-carry of a future contract comprises interest, insurance, and commission (cost-of-carry also include storage costs for a commodity such as wheat) that are incurred from holding the contract until settlement.
- Future are more liquid and less subject to default.
- Two contracted parties may not know each other

Forward Market

- Forward contracts are in some aspects similar to Future contracts. They involve an agreement to buy or sell an asset on a certain date for certain price.
- Future contracts are traded on an organized exchange, and the terms of the contract are standardized by the exchange. By contrast, forward contracts are private agreements between two financial institutions or between a financial institution and one of its corporate clients. Usually, in forward contracts, there is a range of possible delivery date.
- Forward contracts are not marked to market daily like future contracts. The involved two parties contract to settle up on the specified delivery date. Whereas most future contracts are closed out prior to delivery, most forward contracts do lead to delivery of the physical asset or to final settlement in cash.

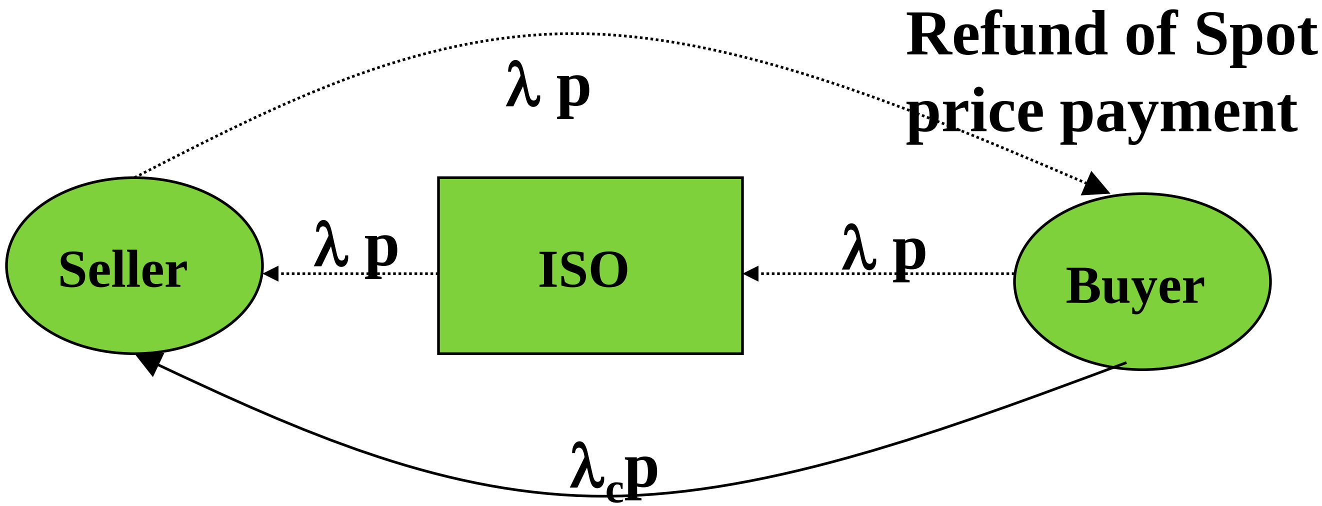
- It appears that forward contracts are more manageable than future markets in the electricity market. Some research work has been done in this respect, such as forward contracts under spot pricing, and optional forward contracts (callable forward contracts).

Forward	Future
Private contract between two parties	Traded on an exchange
Not standardized	Standardized contract
Range of delivery dates	Usually one specified delivery date
Settled at end of contract	Settled daily
Delivery or final cash settlement usually takes place	Contract usually closed out prior to maturity

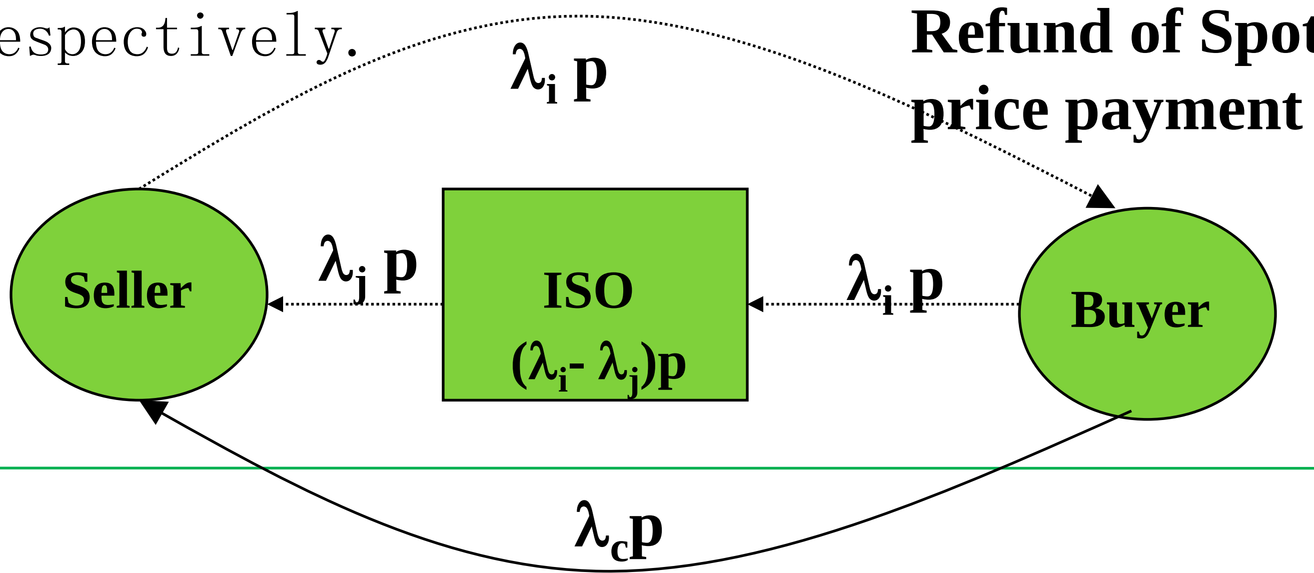
Contract for Difference (CfD)

- A CfD assumes the existence of an underlying spot market.
- The purpose of CfD is to eliminate uncertainty in temporal spot price variation.
- **Definition**: A CfD between a buyer and seller involves a payment by the buyer to the seller of $p(\lambda_c - \lambda)$ where λ is the spot price and λ_c is the contract price.

- If spot price at buyer's and seller's bus is λ.



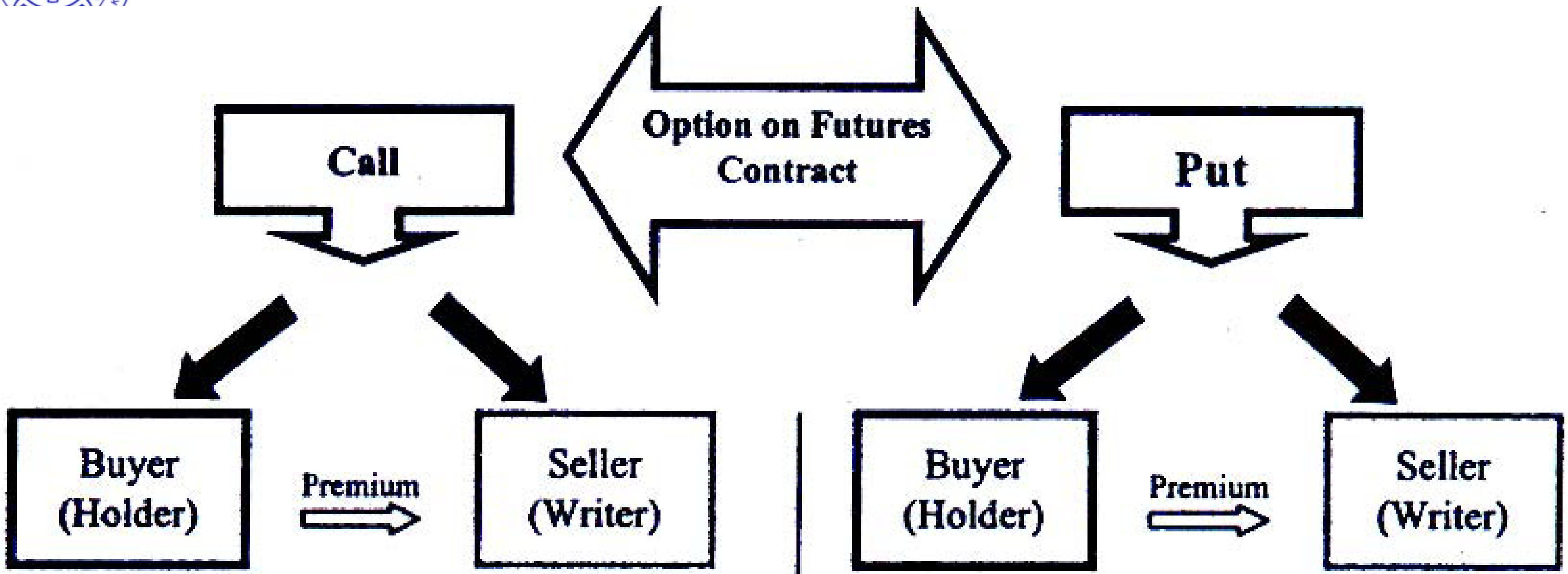
- If spot price at buyer's and seller's bus is λ_I and λ_j respectively.



Option Contract

- Options contracts are also tradable instruments which grants the holder the right, but not the obligation, to either buy or sell an underlying security, such as a future contract, or commodity at an agreed upon price at some future point in time.
- The agreed upon price is known as the **strike price** and is established at the time of purchase. The future point in time at which the option may be exercised is know as the expiration date.
- The buyer of the option pays a **fee or premium** to the seller. A call option gives the holder the right to purchase the underlying property at some future date, and a put option gives the holder the right to sell the property at some future date.

- Options can be held in isolation. Speculators and hedgers both participate in the options market. Since options contracts are tradable, the holder has the flexibility to sell the contract in a secondary market.
- In the electricity market, option contracts can also be used to mitigate risks of supply and price. However, option contracts are financial instruments and are not directly related to the physical delivery of electricity.
- The holder does not have to exercise this right. This fact distinguishes options from future contracts.



Call – Buyer (Holder)

- Believes the market electricity price may rise
- Has the right to buy futures if he/she chooses to exercise (if the buyer chooses to purchase futures)

Call – Seller (Writer)

- Believes the market electricity price may fall or stay stable
- Obligated to sell futures contract if option is exercised (if the buyer chooses to purchase futures)

Put – Buyer (Holder)

- Believes the market electricity price may fall
- Has the right to sell futures if he/she chooses to exercise (if the buyer chooses to sell futures)

Put – Seller (Writer)

- Believes the market electricity price may rise or stay stable
- Obligated to buy futures contract if option is exercised (if the buyer chooses to sell futures)

Demand Elasticity

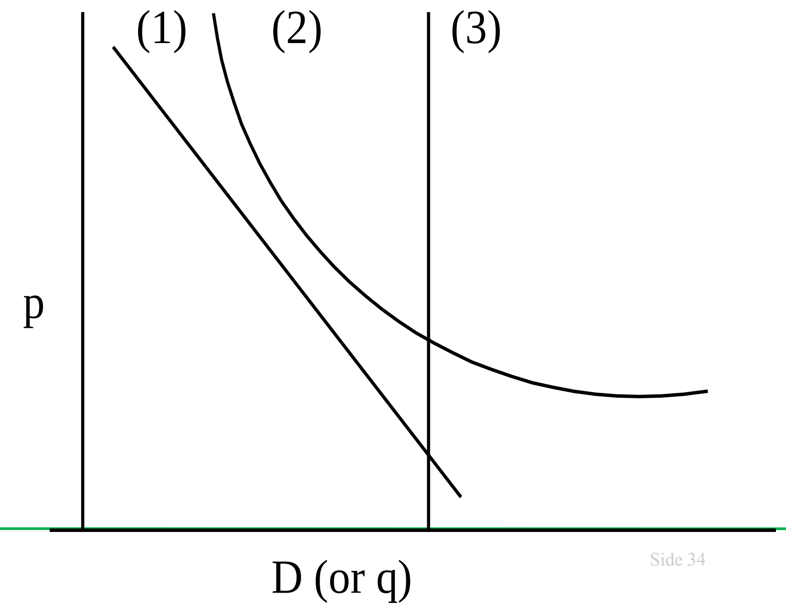
- It is defined as ratio of percentage change in the demand to the % change in price that causes it.

$$e = -\frac{\Delta D\%}{\Delta p\%} = -\frac{\Delta D / D}{\Delta p / p} = -\frac{p}{D}\frac{\Delta D}{\Delta p} = -\frac{p}{D}\frac{dD}{dp}$$

- Negative sign is used to show the elasticity is positive.
- Examples
- e for curve-1 where $p = -a.D+p_0$

$$e = \left[1 - \left(\frac{p_0}{p - p_0}\right)\right] = not \;\; constatnt$$

- $e = 0$ for curve-3
- e=1 for curve-2 where $D=a/p$

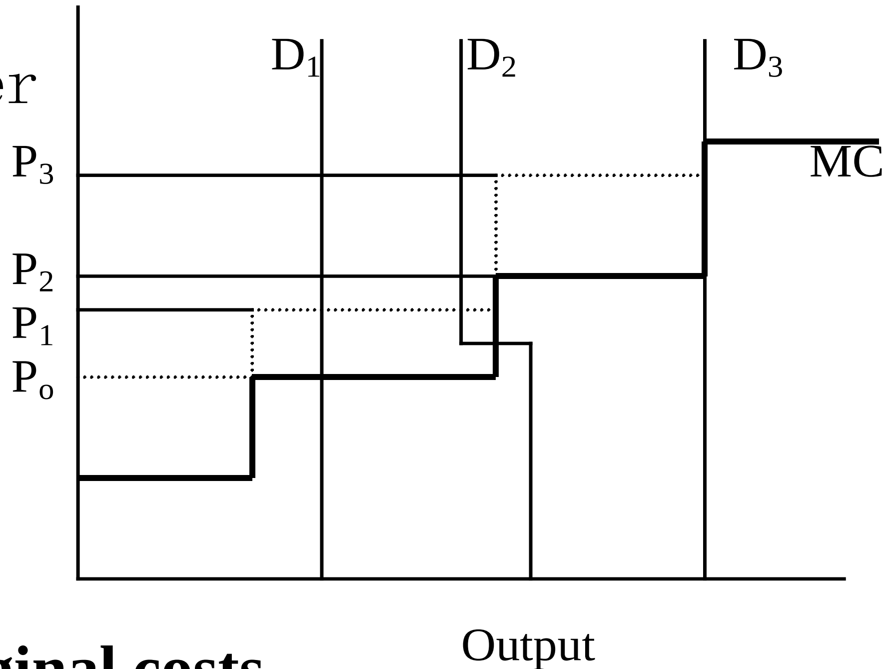


MARKET POWER

- Definitions:
  - Market power is the ability to profit by moving the market price away from the competitive level (economic)
  - Market power to a seller is the ability profitably to maintain prices above competitive level for significant period of time (regulatory)
  - Most of the firms have some market power and this causes no significant problems if the amount of small.
- Effects:
  - Market power raises price and thereby more profit
  - Transfers wealth from customers to **all the suppliers** in the market.

MARKET POWER

- Types
  - Normal Market Power
  - Negative market Power
  - Non-Market Power
  - Vertical market power
  - Horizontal market power



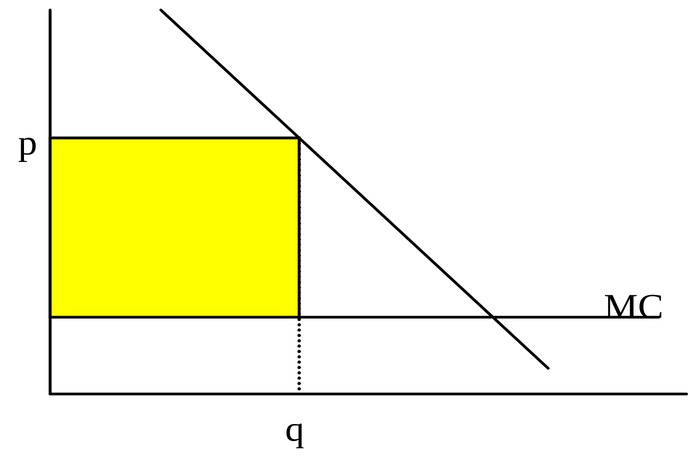
Left hand and right hand marginal costs.

- Marginal Generator can exercise the market power.
- Causes
  - Large generator capacity and low number of particpants
  - Network constraints
  - Additional opportunity to create intentional congestion
- Factors determine the Market power
  - Market concentration
  - Demand elasticity
  - Style of competition
  - Forward contract
  - Geographical extent of market

- Different approaches to study the market power
  - Ex-post analysis of recently restructured market
  - Market concentration analysis
  - Market simulation — ex-ante studies
  - Equilibrium modeling
- Market concentration index
  - Lerner index or price-cost margin (L)
  - Herfindahl-Hirschman Index (HHI)
  - Generalized HHI (GHI)
  - Basic Market Power Index (BPI)
- Lerner Index
  - Measures the markup price above the marginal cost.
  - $1 \geq L \geq 0$
  - Defined as $$L = \frac{p - MC}{p}$$

Lerner Index for Monopoly

- L = 1/e
- Proof:



Let demand curve $p_d = a - m.q$

Profit will be $A = (p_d - MC).q$

$= (a - m.q - MC)q$

For max. profit at q, $dA/dq = 0$

$q = (a - MC)/2m$

or $a = 2m.q + MC$ and

$a = p - MC$

Hence $mq = p - MC$

By definition, $e = -(p/q).(dq/dp) = p/m.q = 1/L$

Hence $L = 1/e$

- # Lerner Index for a Cournot Oligopoly
  - Supplier choose their quantity output. Price is determined by total supply and consumers demand curve. Suppliers max. profits under the assumption that all other supplier will keep their output fixed.
  - There are several suppliers and market share is important. If s= q/Q
  - L = s/e (s =1 for monopoly).
  - Proof ?
- # HHI
  - If s_i is the market share of ith supplier, then over all suppliers.
    $$HHI = \sum_i (s_i)^2$$
  - HHI can be any value between 0 and 1, but in legal documents it is multiplied by 10000.
  - HHI account for only one factor (concentration).
  - GHI can be used

- GHI is the share-weighted average Lerner index of a group of suppliers, assuming all suppliers in the market are cournot competitors and demand elasticity is 1.
- GHI = $\sum s_i L_i$
- BPI
    - The BPI is the basic markup, $(p-p^*)/p$, of a group of suppliers, assuming all suppliers in the market are Cournot competitors and the market demand elasticity is 1. p^* is the competitive price.
    - With constant marginal costs, BPI =HHI
- Market Power mitigation techniques
    - Generation Divestiture
    - Internal re-organization
    - Bidding contracts
    - Demand side bidding

- Price caps
- Bid caps
- Revenue caps
- Contract for differences
  - one way
  - two way

- Market power on demand side
  - Monopsony power is the market power exercised on the demand side with the intention of lowering the market price.
  - An ISO can exercise by interrupting loads or by curtailments
  - Monopsony power can be effective and beneficial method for combating market power but is can also be abused.


THANK YOU