Bidding Strategy in Power Markets

S.N. Singh, *Professor*

Department of Electrical Engineering
Indian Institute of Technology Kanpur
Email: snsingh@iitk.ac.in

- **Electricity market has the following features:**
  - Limited suppliers (power producers)
  - Transmission constraints
    - isolate consumers from effective reach of many generators
    - economically isolate submarkets from the competition of suppliers located elsewhere in the network
    - strategic behavior by the bidders (power suppliers)
  - Transmission losses
    - limit consumers to purchase power from some plants which are far from the consumers (because they need to pay the involved losses)
  - **?????**
- The electricity market may not be a perfectly competitive market, and is likely an oligopoly market, and there is some potential market power in any form of proposed deregulation structures.

- There are the following three main oligopoly market models:
- **Cournot Model**
  - Each supplier bids production quantity, and the market price is a function of the total supply quantity.
  - A perfect market is an extreme case of Cournot model where the number of suppliers are infinite and the price of the market is constant (not a function of the supply quantity).
- ***Bertrand Model:***
  - Each supplier bids price rather than quantity at which it is willing to produce.
  - Lower price will capture the market share and all will have equal shares at equal price.

- Let for two players, x(p) is the demand function, the profit or payoff of one will be

$$\lambda_1(p_1, p_2) = \begin{cases} p_1 x(p_1) & if \quad p_1 < p_2 \\ p_1 x(p_1)/2 & if \quad p_1 = p_2 \\ 0 & if \quad p_1 > p_2 \end{cases}$$

- It is similar to prisoner's dilemma. If both players cooperate, they can both change the monopoly price. By reducing the price one can capture the market.

- ***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 allows explicit representation of a number of important aspects, like the sequencing of players' possible moves, their choices at every decision point; the information each player has about the other player's moves when he makes a decision, and his payoffs for all possible game outcomes.
- normal or strategic forms (*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*).
- Payoff for a player depends not only on chosen strategies by that player but also on the strategies by the others.
- Rule of game, strategies available to players and payoff are common knowledge.
- Each player must act rationally to maximize its profit.

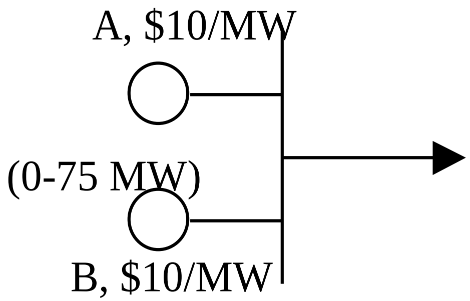
- *Example-1*
  - Let genenerator-1 has capacity of 100 MW with production cost \$75/MW per unit time. Demand is 100 MW. Bid of other gen at the same bus is

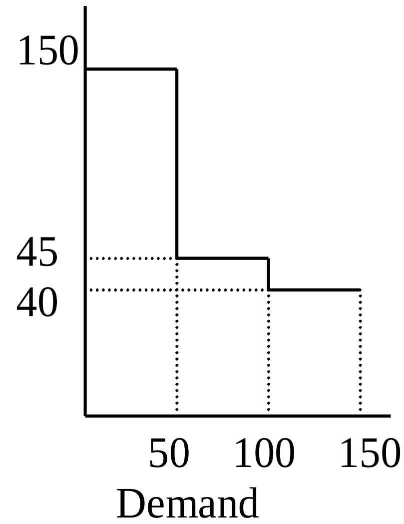
50 MW	101 \$/MW
50 MW	121 \$/MW

- *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	
Gen. A	Low	45	150	

- *Profits*

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

Demand elasticity

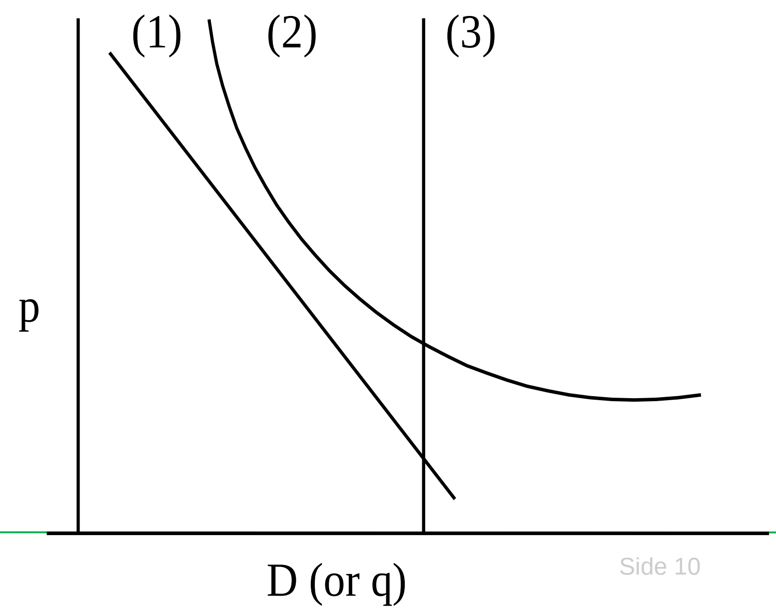
- It is defined as ratio of percentage change in the demand to the % change in price that causes it.

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

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

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

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



Bidding Strategies

- Deterministic formulation
  - Assumptions
    - uncertainty are not included
    - No temporalities
    - All rivals are clubbed together
  - Rival:
    - Block: $\phi_1, \phi_2, \ldots\ldots\ldots, \phi_J$ MW
    - Price : $\rho_1, \rho_2, \ldots\ldots, \rho_J$ \$/MW ($\rho_{j+1} > \rho_j$; $\forall j$)
  - Seller:
    - Block: $H_1, H_2, \ldots\ldots\ldots, H_I$ MW
    - Cost : $c_1, c_2, \ldots\ldots, c_I$ \$/MW ($c_{i+1} > c_i$; $\forall i$)
    - Bids : $p_1, p_2, \ldots\ldots, p_I$ \$/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.

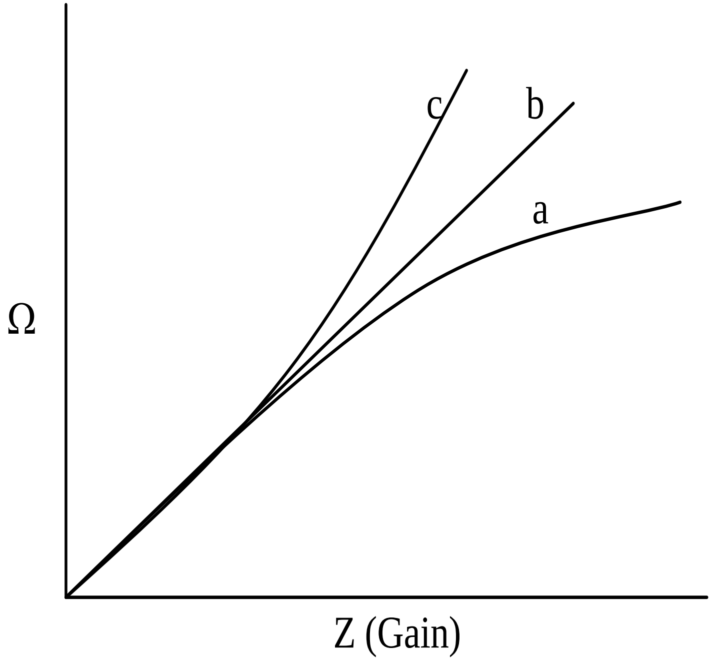
$$v_i = \begin{cases} 1 & iff \left\{ \begin{array}{l} (p_i > \rho_j) \text{and} (p_i < \rho_{j+1}), and \\ \sum_{k=1}^{j} \phi_k + \sum_{k'=1}^{i-1} H_{k'} \leq D \end{array} \right\} \\ 0 & \text{otherwise} \end{cases}$$

- 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 waw offered at price p_i

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

- 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 MW C_1 = \$50/MWh
H_2 =200 MW C_2 = \$65/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

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

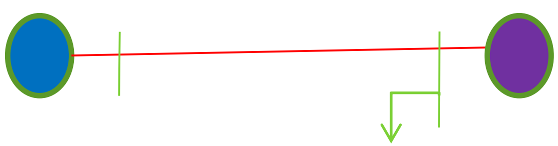
$$v_i = \begin{cases} 1 & iff \left\{ \begin{array}{l} (p_i > \rho_j)\text{and}(p_i < \rho_{j+1}), and \\ \sum_{k=1}^{j} \phi_k + \sum_{k'=1}^{i-1} H_{k'} \le D \end{array} \right\} \\ 0 & \text{otherwise} \end{cases}$$

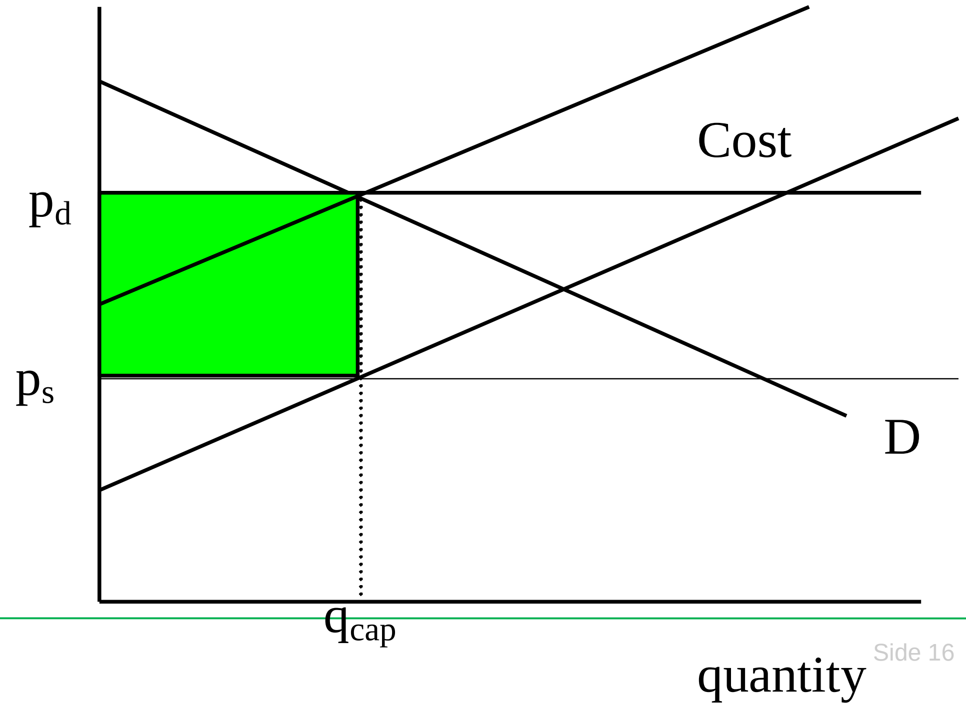
Options are

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

Bidding in a constrained network

- **Transmission constraints restricts the flow of power from low cost node to high value nodes.**
- **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.**
- **Unsubscribed revenue can be given to transmission right holders.**





G1= 10 \$, G2=12 \$

$P_{flowlimit}$ = 100 MW,

Load is 120 MW

- Types of Generation Competition
  - Perfect Competition (max. welfare) solution: bid curve provided by each producer is equal to its marginal cost function.
  - Imperfect Competition solution:
    - Each gen. chooses the supply function bid that maximize it profit given a fixed set of rivals bids.
    - A Nash equilibrium occurs at a point where no generator can increase profits by changing the its bids.
  - Monopoly solution: there is s single owner of all generation.

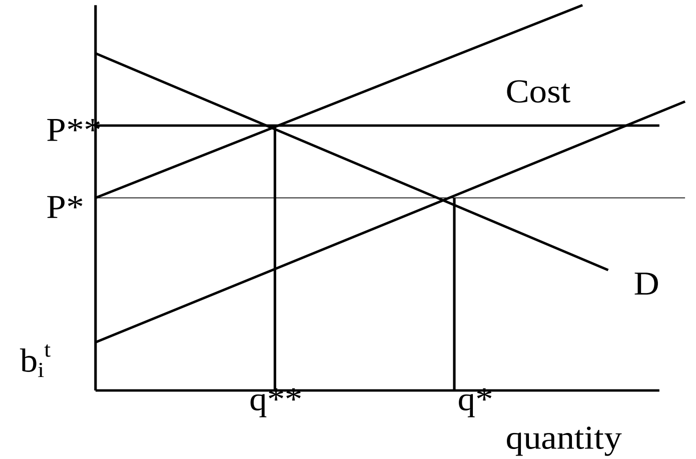
Imperfect competition and strategic Bidding

- 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

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

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

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



- 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

Example: Block Biding-Double Sided

- DisCo1 bid

Price ($/MWh)	Demand (MW)
0	70
40	70

DisCo2 Bid

Price ($/MWh)	Demand (MW)
0	80
22.5	80
30	65
35	65
37.5 40	60 60

- Aggregated Bid

Price ($/MWh)	Demand Disco 1 (MW)	Demand Disco 2 (MW)	Aggregated Demand (MW)
0	70	80	150
22.5	70	80	150
30	70	65	135
35	70	65	135
37.5 40	70 70	60 60	130 130

Example: Block Biding-Double Sided

- GenCo1 bid

Price ($/MWh)	Supply (MW)
0	15
19.99	15
20	90
40	90

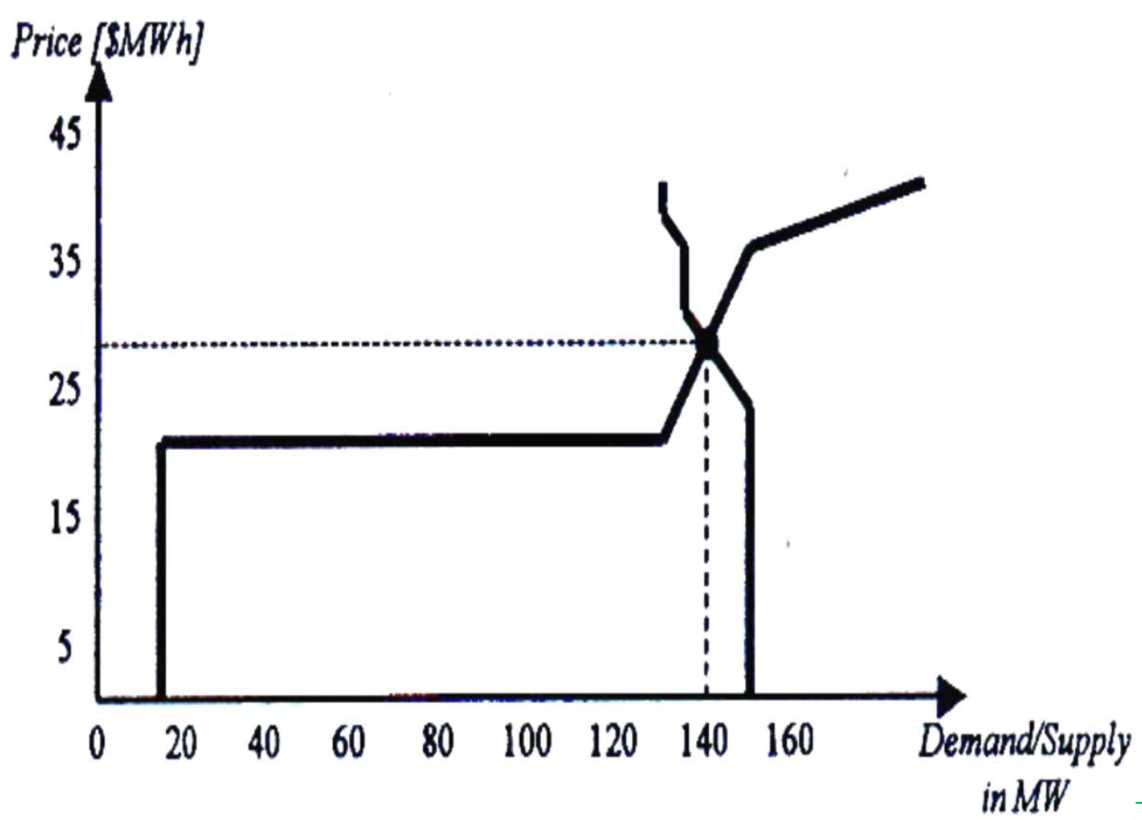
GenCo2 Bid

Price ($/MWh)	Supply (MW)
0	0
19.99	0
20	40
35	60
40	100

- Aggregated Bid

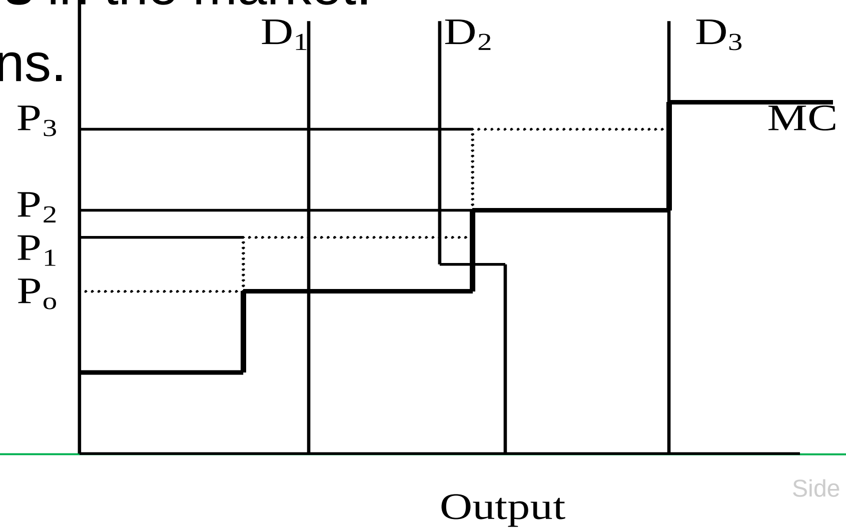
Price ($/MWh)	Supply Genco 1 (MW)	Supply Genco 2 (MW)	Aggregated Supply (MW)
0	15	0	15
19.99	15	0	15
20	90	40	130
335	90	60	150
40	90	80	190

- Market clearing price = 27.5 $/MWh
- Total traded power = 140 MW
- G1 = 90 MW, G2=50 MW
- D1=70 MW, D2=70 MW



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 transfers wealth from customers to **all the suppliers** in the market.
  - Inefficiency of market (low cons.



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

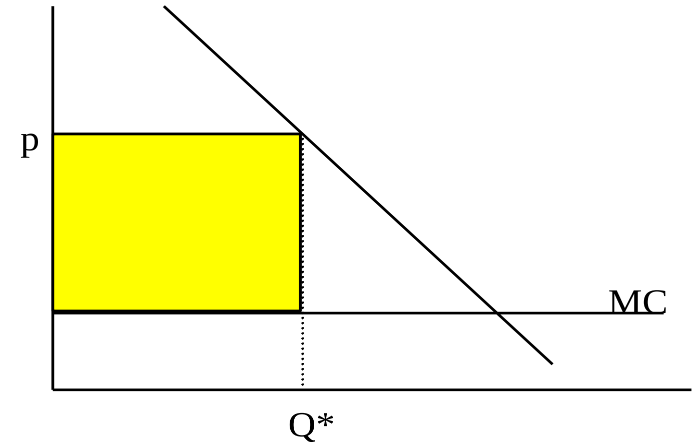
- Marginal Generator can exercise the market power.
- Left hand and right hand marginal costs.
- Causes
  - Large generator capacity
  - Network constraints
  - Additional opportunity to create intentional congestion
- Factors determine the Market power
  - Market concentration
  - demand elasticity
  - 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.d

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 $HHI = \sum_i (s_i)^2$ over all suppliers.
  - 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 and floors
- 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 ISI 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