

Auction Basics for Wholesale Power Markets: Objectives and Pricing Rules

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Presenter

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<https://www2.econ.iastate.edu/tesfatsi/>

Presentation Slides

<https://www2.econ.iastate.edu/tesfatsi/AuctionTalk.LT.pdf>

Presentation Outline

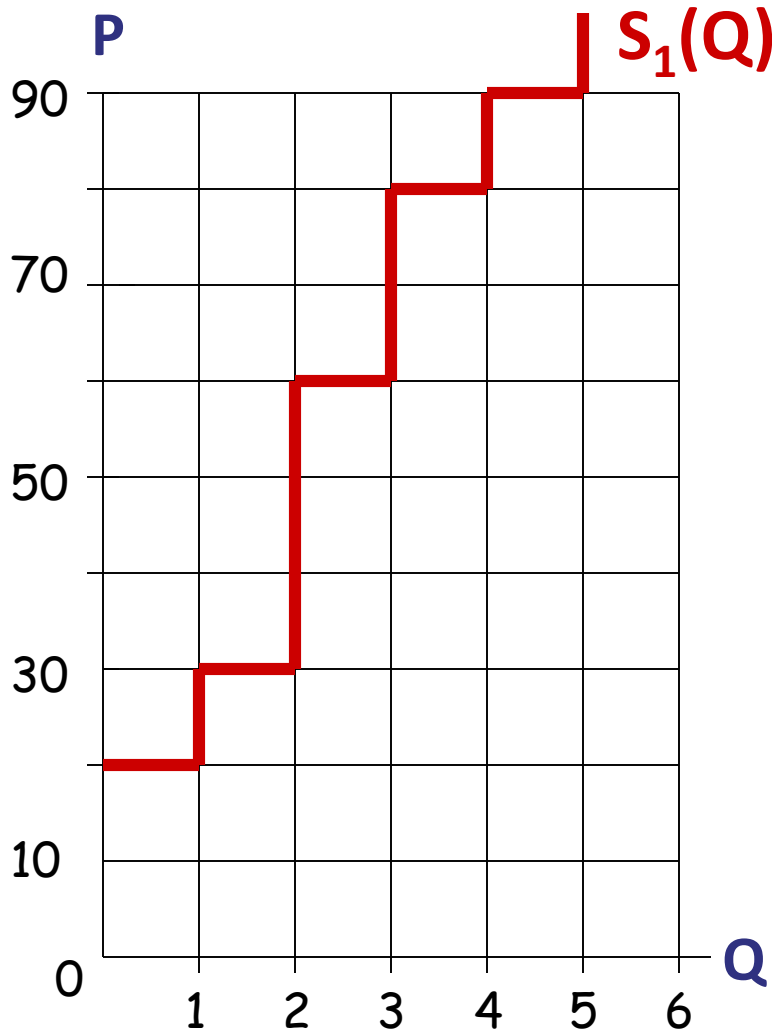
- Introduction
- Double auction basics for energy markets
 - Supply, demand, & market equilibrium
 - Net surplus extraction
- Market efficiency vs. social welfare:
Implications for ISOs in energy markets
- Illustrative experimental results for a
5-bus test case with learning generators

Introduction

- ◆ In many regions of U.S., wholesale electric energy -- measured in megawatt-hours (MWh) -- is transacted in “day-ahead” markets designed as double auctions.
- ◆ **Double Auction** = A centrally-cleared market in which sellers make supply offers & buyers make demand bids.
- ◆ After review of basic double auction concepts, efficiency & welfare issues arising from use of double auctions for centrally-managed day-ahead markets for energy will be discussed.

DOUBLE-AUCTION BASICS: EXAMPLE

Seller 1's Supply Offer: $P = S_1(Q)$, where $P = \text{Price}$ and $Q = \text{Quantity}$



$Q = \text{Quantity}$ of specialty apples (in bushels)
 $P = \text{Price}$ of specialty apples (\$ per bushel)

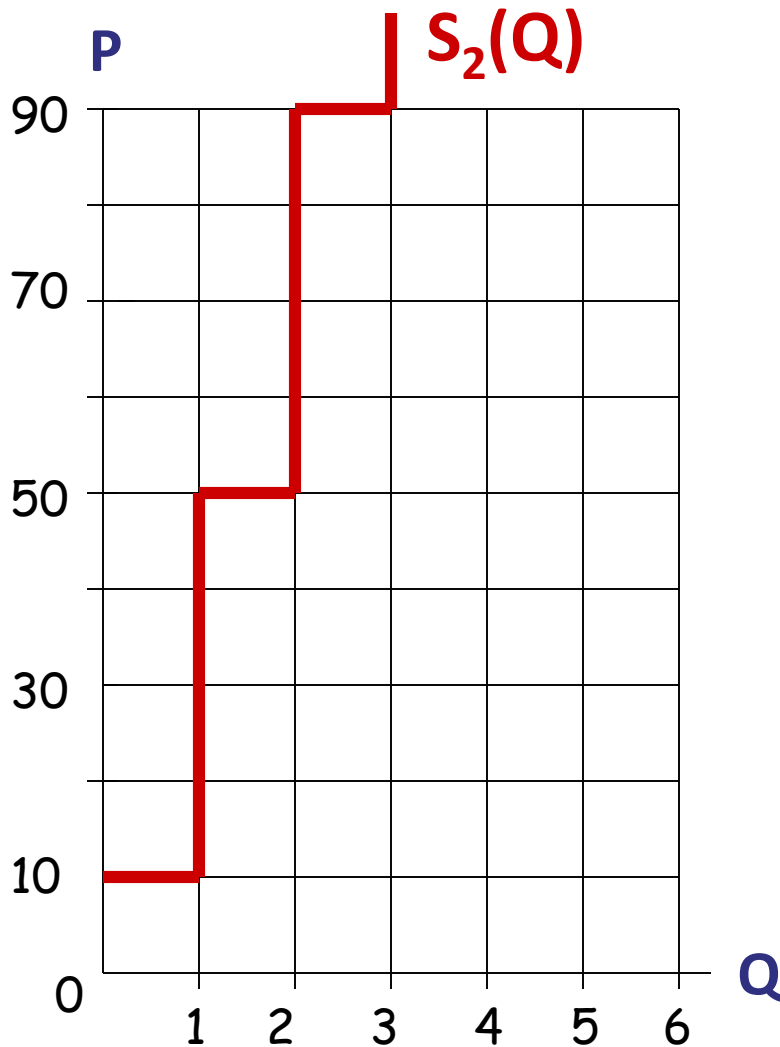
For each Q : $P = S_1(Q)$ is Seller 1's **minimum acceptable sale price** for the "last" bushel it supplies at Q .

Bushels Q	Price $P = S_1(Q)$
1	\$20
2	\$30
3	\$60
4	\$80
5	\$90
6	∞

5 bushels = Seller S_1 's max possible supply.

Note: "Minimum acceptable sale price" is also called a "(sale) reservation value"

Seller 2's Supply Offer: $P = S_2(Q)$, where $P = \text{Price}$ and $Q = \text{Quantity}$



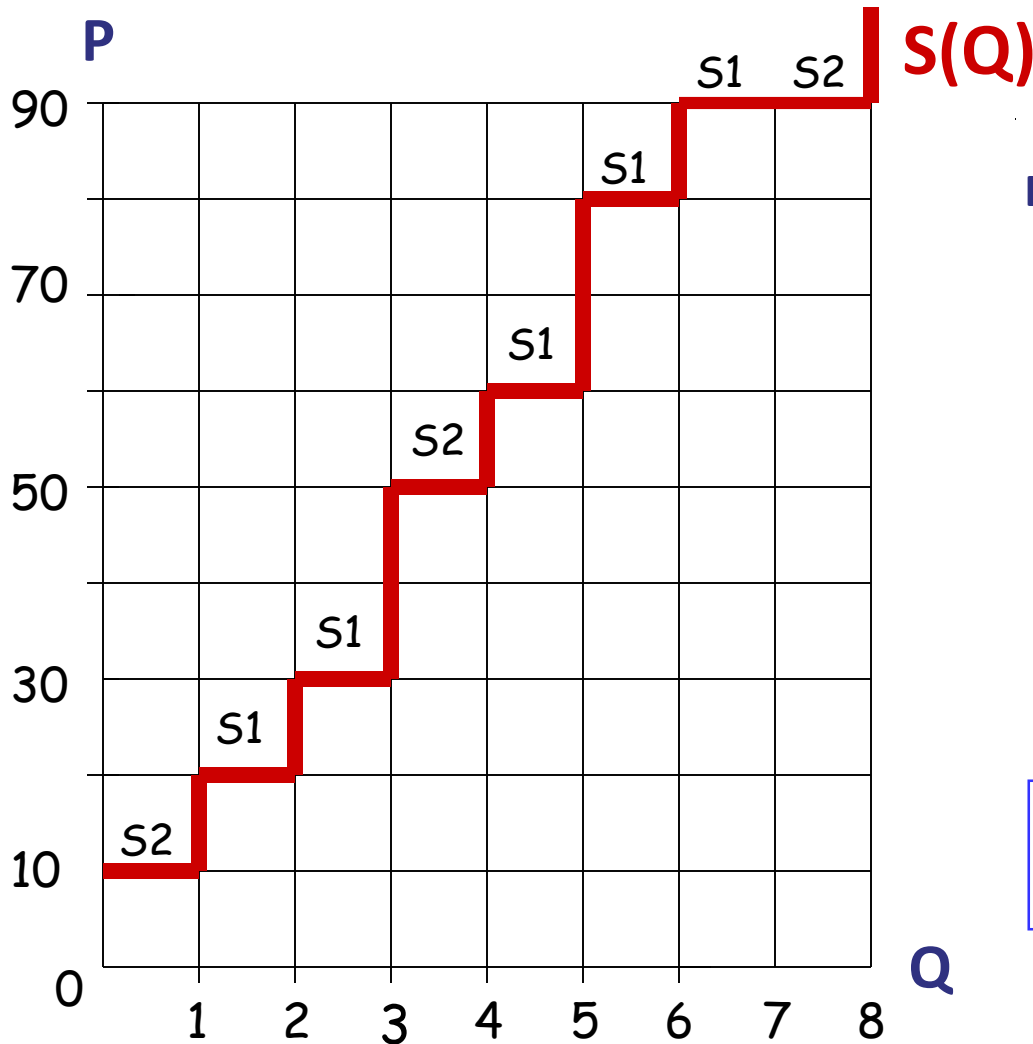
For each Q : $P = S_2(Q)$ is Seller 2's *minimum acceptable sale price* for the last bushel it supplies at Q .

Bushels Q Price $P = S_2(Q)$

1	\$10
2	\$50
3	\$90
4	∞

3 bushels = Seller S_2 's
max possible supply.

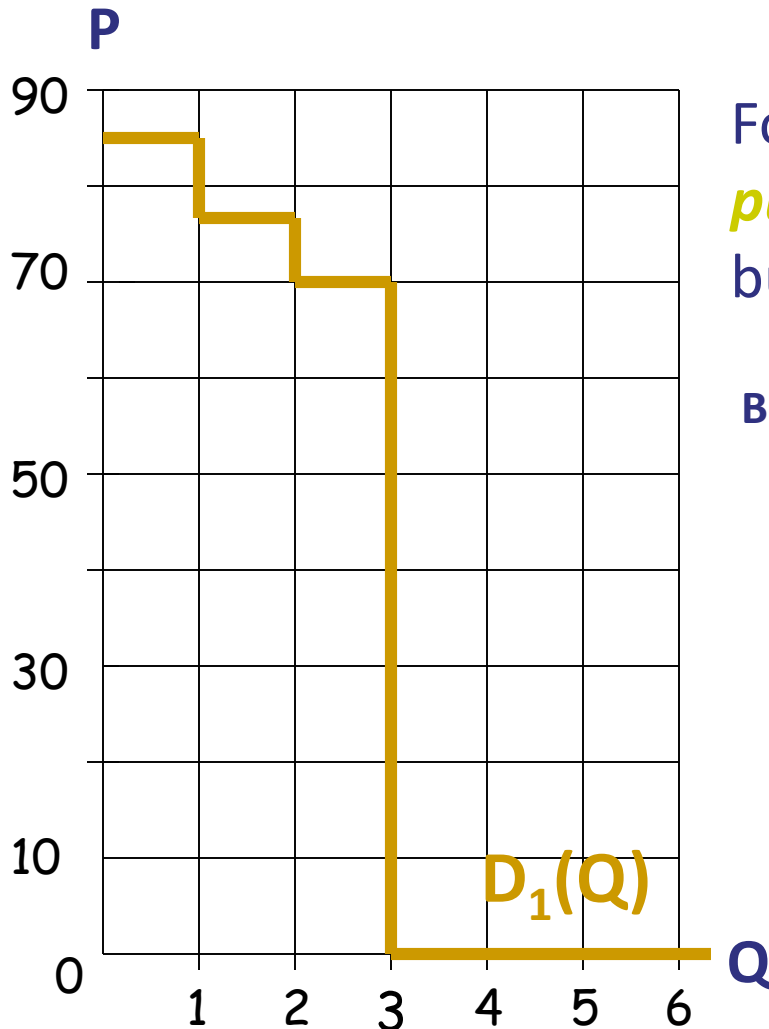
Total System (Inverse) Supply Function: $P = S(Q)$



Bushels Q	Price P = S(Q)
1	\$10 (S2)
2	\$20 (S1)
3	\$30 (S1)
4	\$50 (S2)
5	\$60 (S1)
6	\$80 (S1)
7	\$90 (S1/S2)
8	\$90 (S2/S1)
9	∞

Max possible total market supply = 8 bushels of apples.

Buyer 1's Demand Bid: $P = D_1(Q)$, where $P = \text{Price}$ and $Q = \text{Quantity}$



For each Q : $P = D_1(Q)$ is Buyer 1's **max purchase price** (\$/bushel) for the last bushel it purchases at Q .

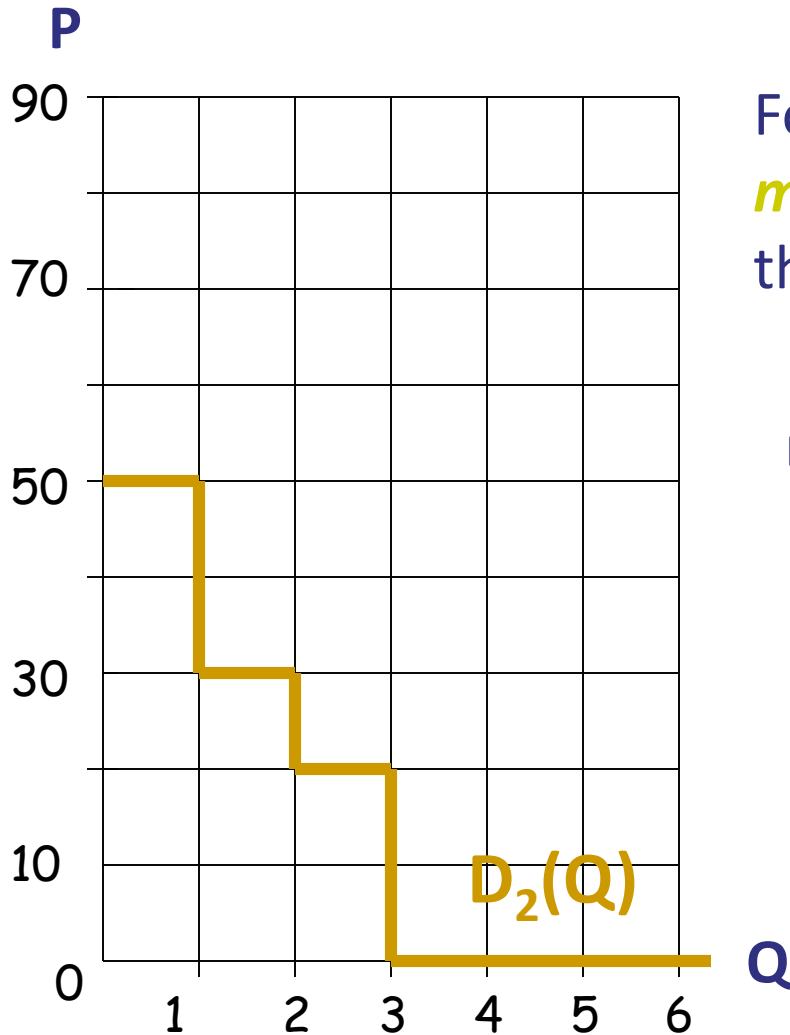
Bushels Q Price $P = D_1(Q)$

1	\$84
2	\$76
3	\$70
4	\$ 0

Buyer 1's demand for apples is "satiated" at 3 bushels.

Note: "Maximum purchase price" \equiv "maximum willingness to pay" is also called a "(purchase) reservation value."

Buyer 2's Demand Bid: $P = D_2(Q)$, where $P = \text{Price}$ and $Q = \text{Quantity}$



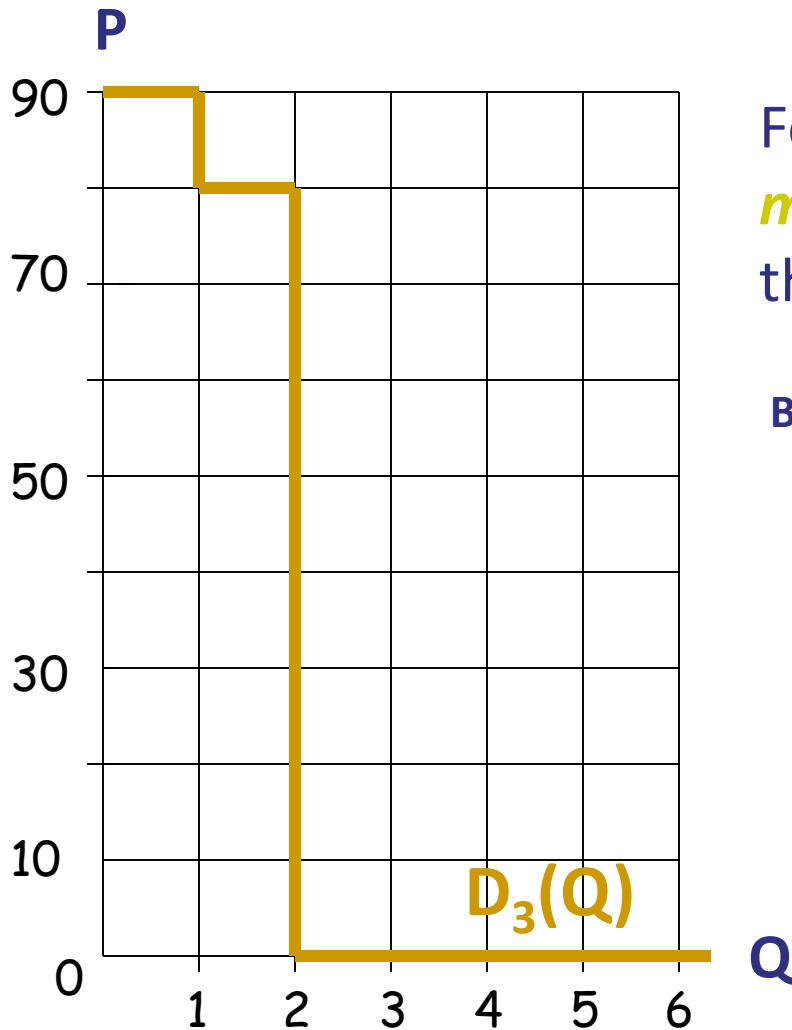
For each Q : $P = D_2(Q)$ is Buyer 2's **max purchase price** (\$/bushel) for the last bushel it purchases at Q .

Bushels Q Price $P = D_2(Q)$

1	\$50
2	\$30
3	\$20
4	\$ 0

Buyer 2's demand for apples is "satiated" at 3 bushels.

Buyer 3's Demand Bid: $P = D_3(Q)$, where P =Price and Q = Quantity



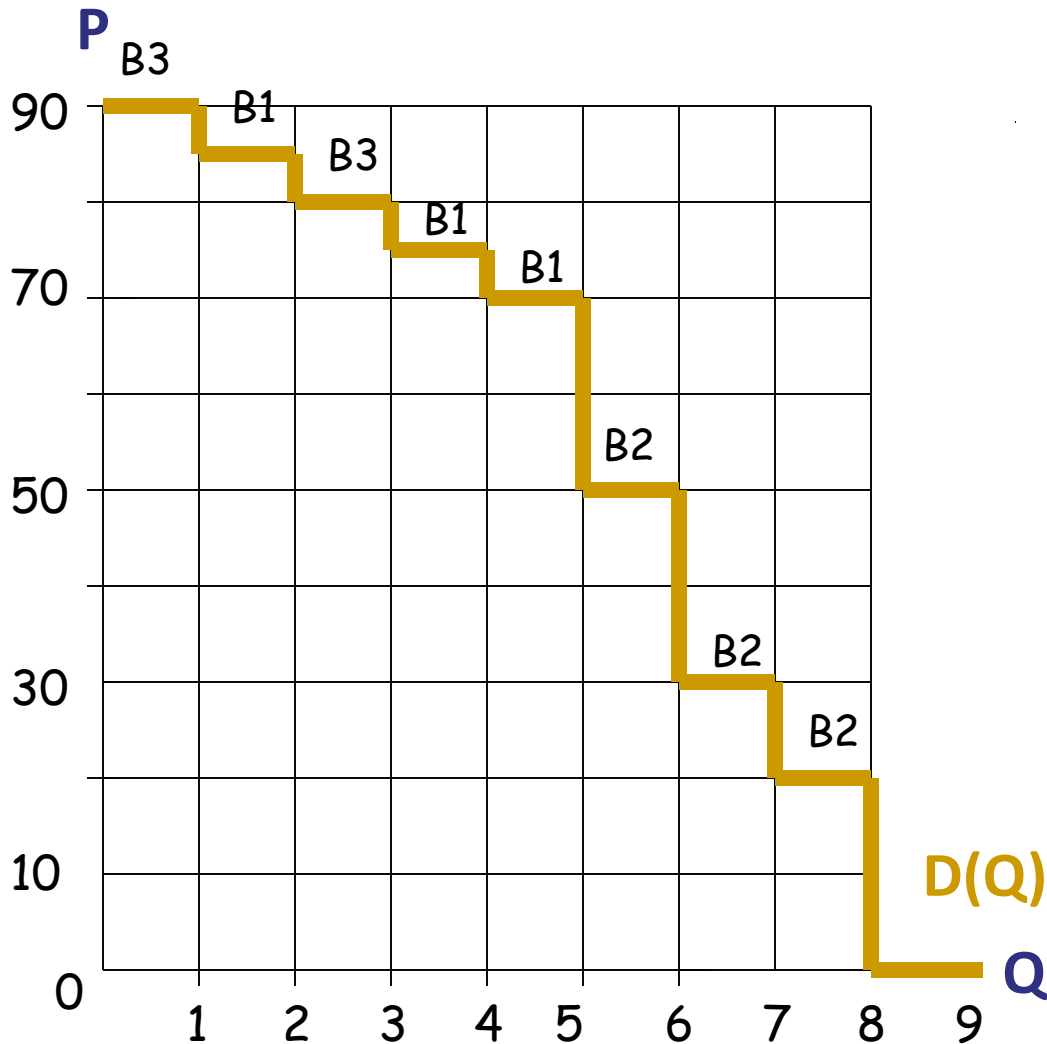
For each Q : $P = D_3(Q)$ is Buyer 3's **max purchase price** (\$/bushel) for the last bushel it purchases at Q

Bushels Q Price $P = D_3(Q)$

1	\$90
2	\$80
3	\$ 0

Buyer 3's demand for apples is "satiated" at 2 bushels.

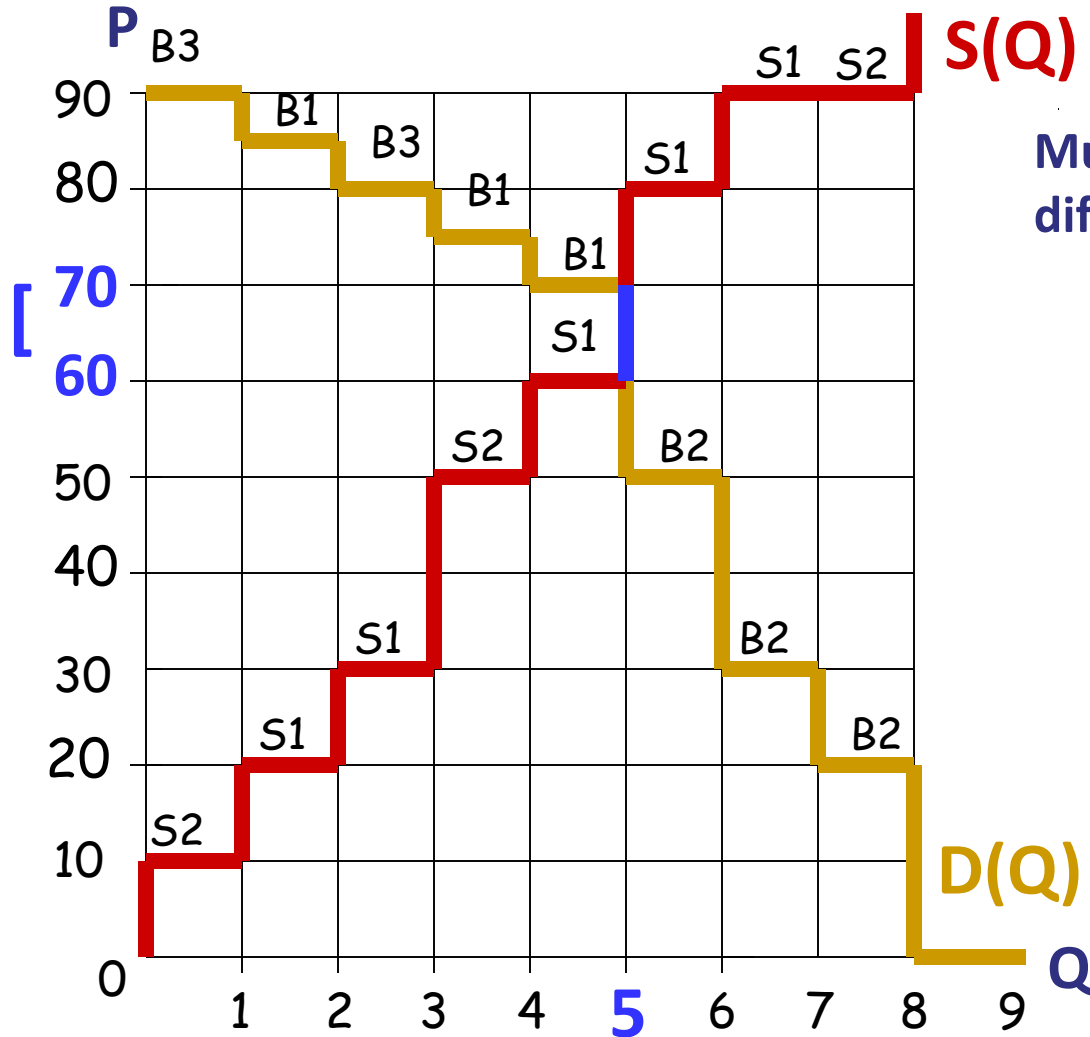
Total System (Inverse) Demand Function: $P = D(Q)$



Bushels Q	Price $P = D(Q)$
1	\$90 (B3)
2	\$84 (B1)
3	\$80 (B3)
4	\$76 (B1)
5	\$70 (B1)
6	\$50 (B2)
7	\$30 (B2)
8	\$20 (B2)
9	\$ 0

Competitive Market Clearing (CMC) Points

Points (Q,P) where the aggregate supply curve $P = S(Q)$ intersects the aggregate demand curve $P = D(Q)$: $P = S(Q) = D(Q)$



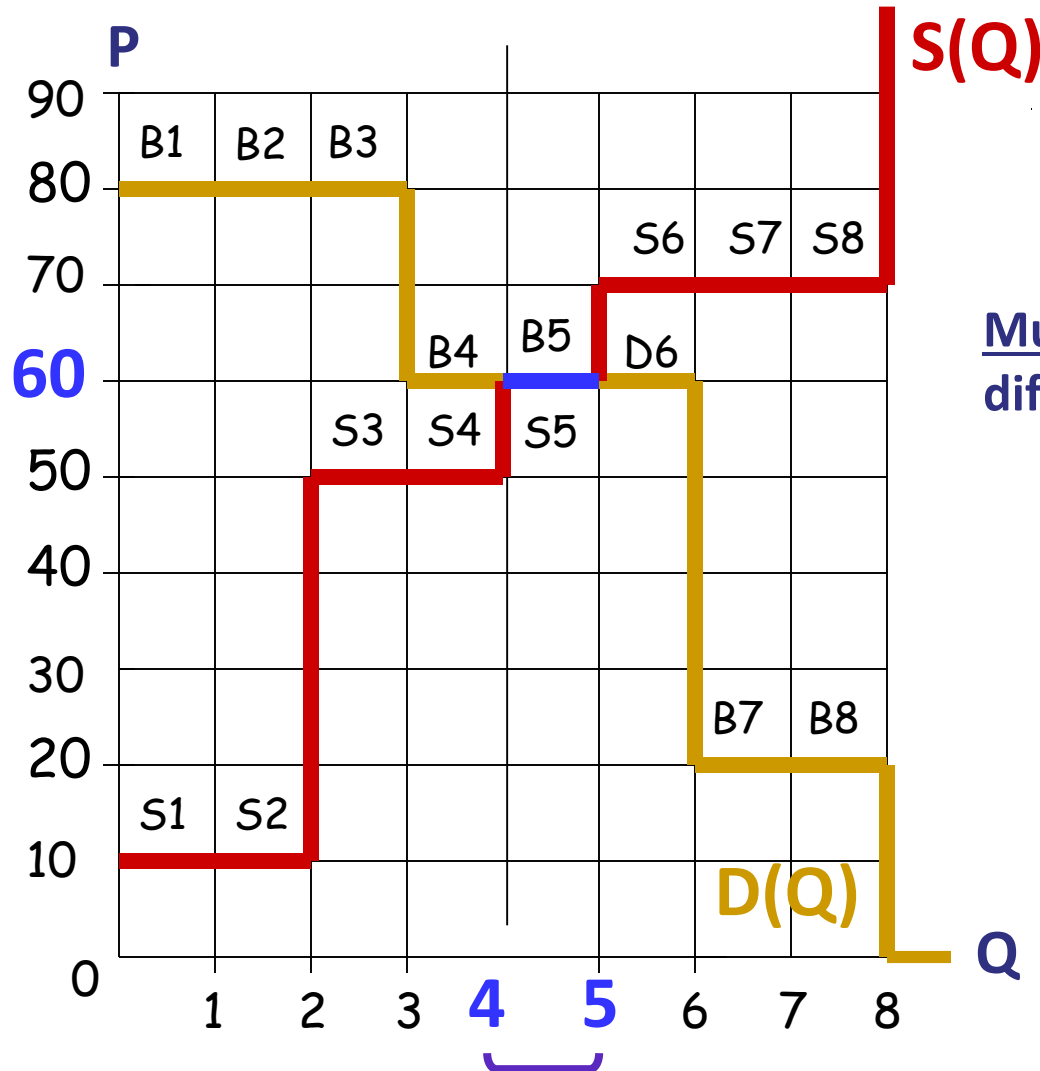
Multiple CMC points (Q^*, P^*) with different CMC prices P^* :

$$Q^* = 5, \$60 \leq P^* \leq \$70$$

Bushels Q	Max Buy P	Min Sell P
1	\$90	\$10
2	\$84	\$20
3	\$80	\$30
4	\$76	\$50
5	\$70	\$60
6	\$50	\$80
7	\$30	\$90
8	\$20	\$90
9	0	∞

No bushel sales are possible beyond five bushels !

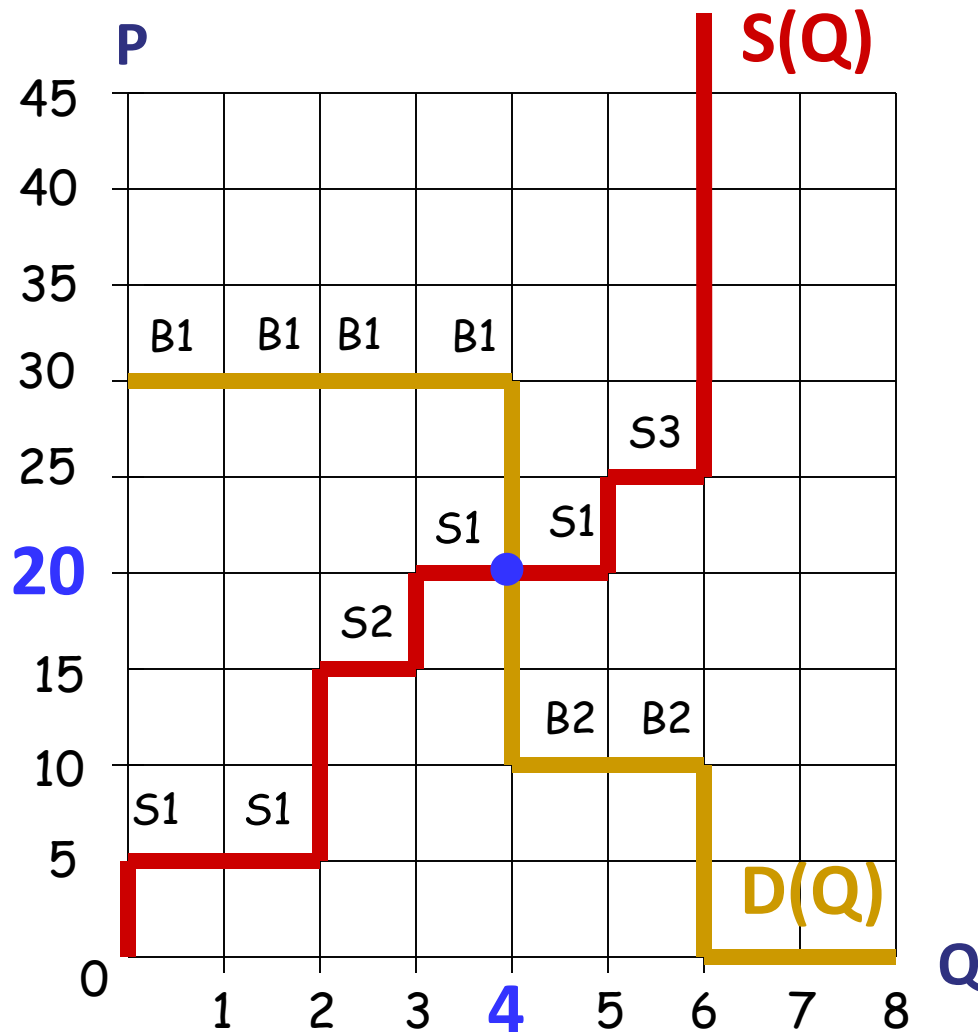
Can also possibly have multiple CMC points with a range of CMC quantities



Multiple CMC points (Q^*, P^*) with
different CMC quantities Q^* :

$$4 \leq Q^* \leq 5, P^* = \$60$$

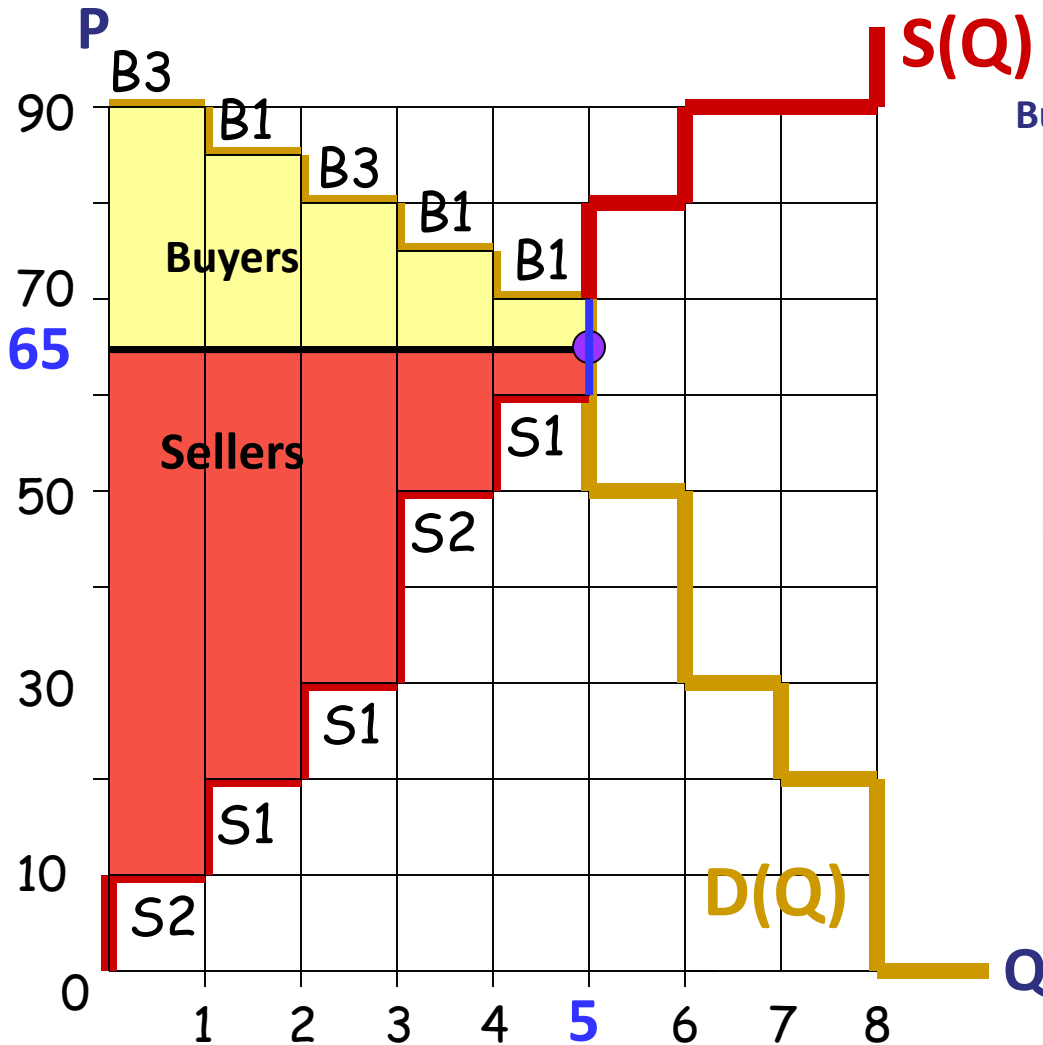
Can also possibly have a unique CMC point



Unique CMC Point:

$$Q^*=4, P^*=\$20$$

Seller & Buyer Net Surplus Amounts at CMC Points



Ex 1: CMC Point $Q^=5, P^*=\$65$*

Bushels Q	MaxBPrice	$P^*=65$	BuyNetSur
1	\$90	- \$65	= \$25
2	\$84	- \$65	= \$19
3	\$80	- \$65	= \$15
4	\$76	- \$65	= \$11
5	\$70	- \$65	= \$5

BUYER NET SURPLUS: \$75

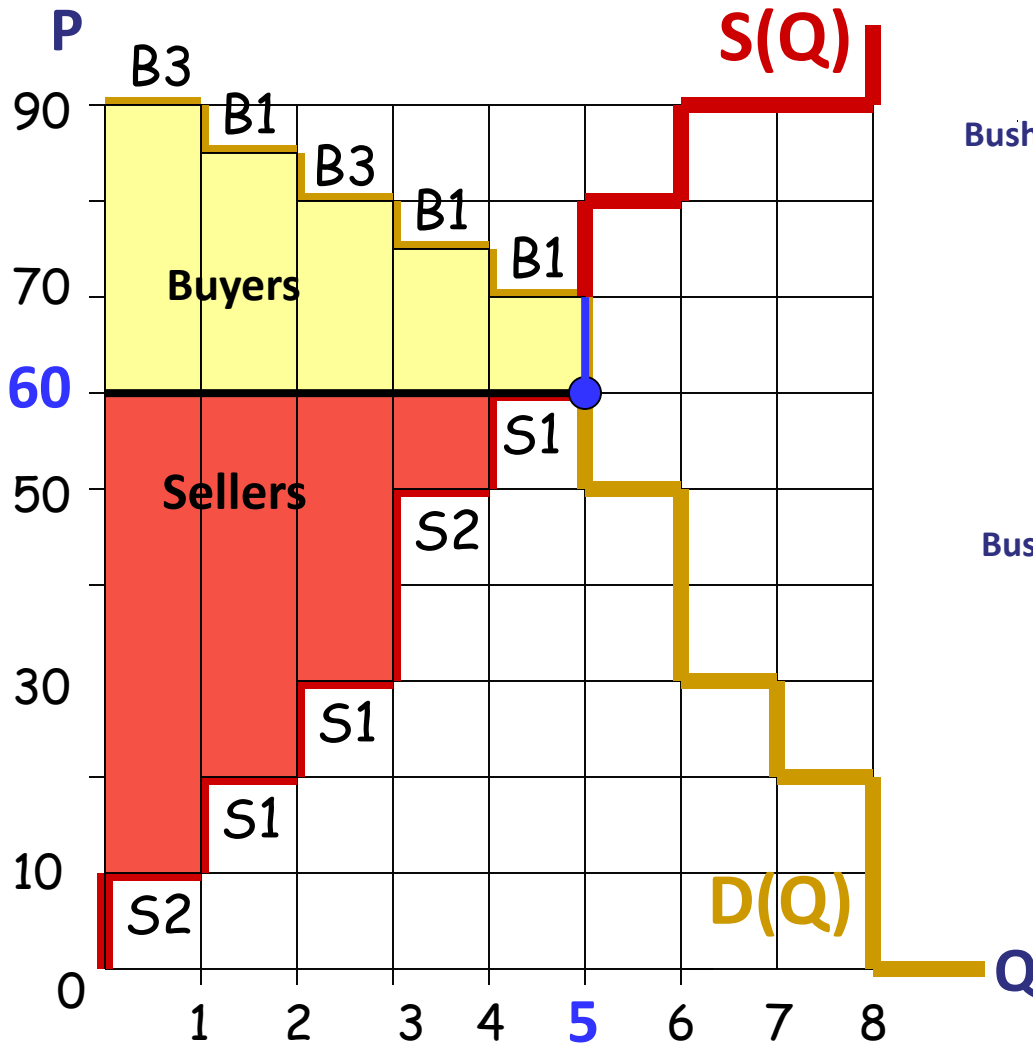
Bushels Q	$P^*=65$	MinSPrice	SellNetSur
1	\$65	- \$10	= \$55
2	\$65	- \$20	= \$45
3	\$65	- \$30	= \$35
4	\$65	- \$50	= \$15
5	\$65	- \$60	= \$5

SELLER NET SURPLUS: \$155

Total Net Surplus: \$230

A *different* selected CMC point

→ *different* seller & buyer net surplus amounts



Ex 2: CMC Point $Q^*=5$, $P^*=\$60$

Bushels Q	MaxBuyPrice	$P^*=60$	BuyNetSurplus
1	\$90	- \$60	= \$30
2	\$84	- \$60	= \$24
3	\$80	- \$60	= \$20
4	\$76	- \$60	= \$16
5	\$70	- \$60	= \$10

BUYER NET SURPLUS: \$100

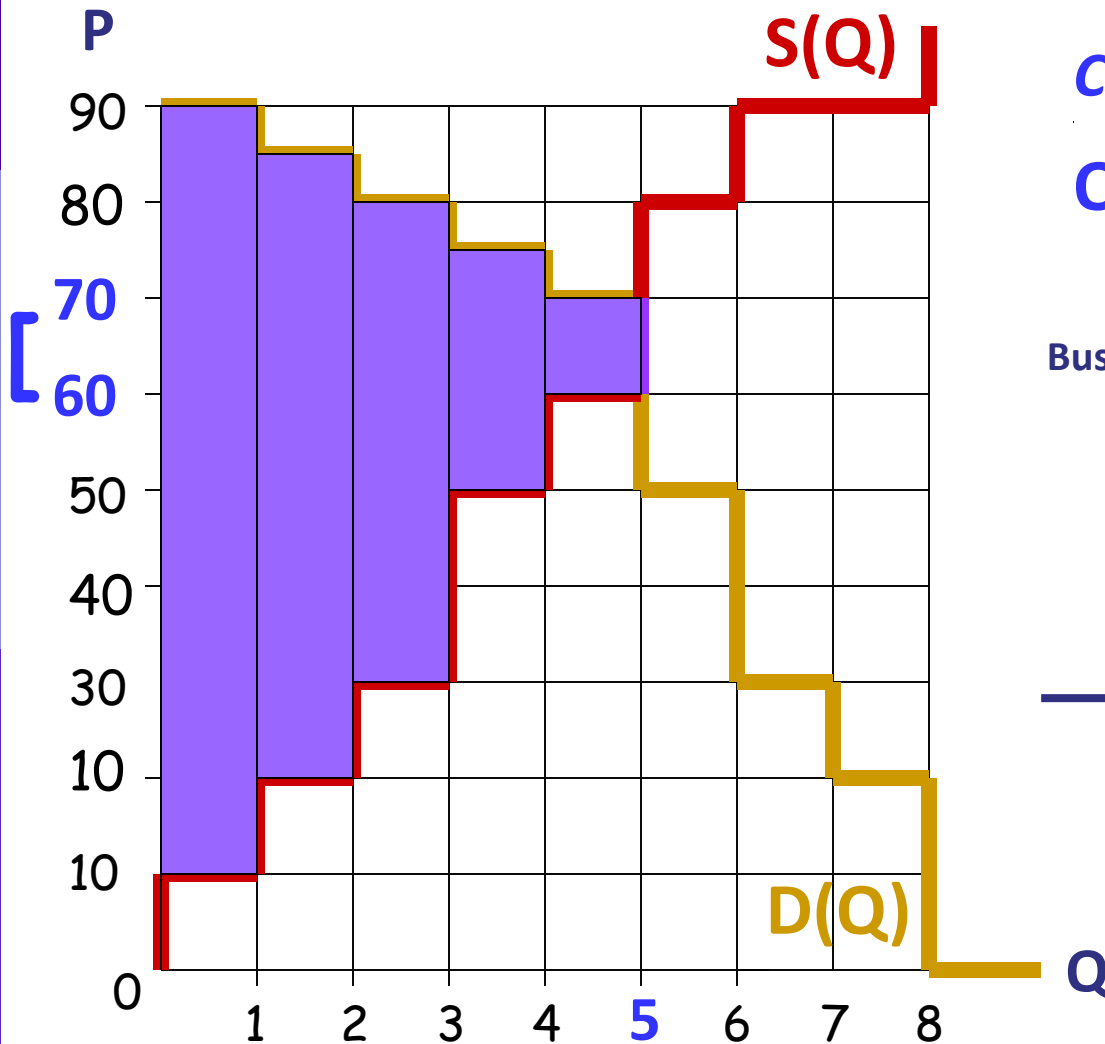
Bushels Q	$P^*=65$	MinSellPrice	SellNetSurplus
1	\$60	- \$10	= \$50
2	\$60	- \$20	= \$40
3	\$60	- \$30	= \$30
4	\$60	- \$50	= \$10
5	\$60	- \$60	= \$0

SELLER NET SURPLUS: \$130

Total Net Surplus: \$230

Total Net Surplus at a CMC Point

(If multiple CMC points exist, TNS = same for each point.)



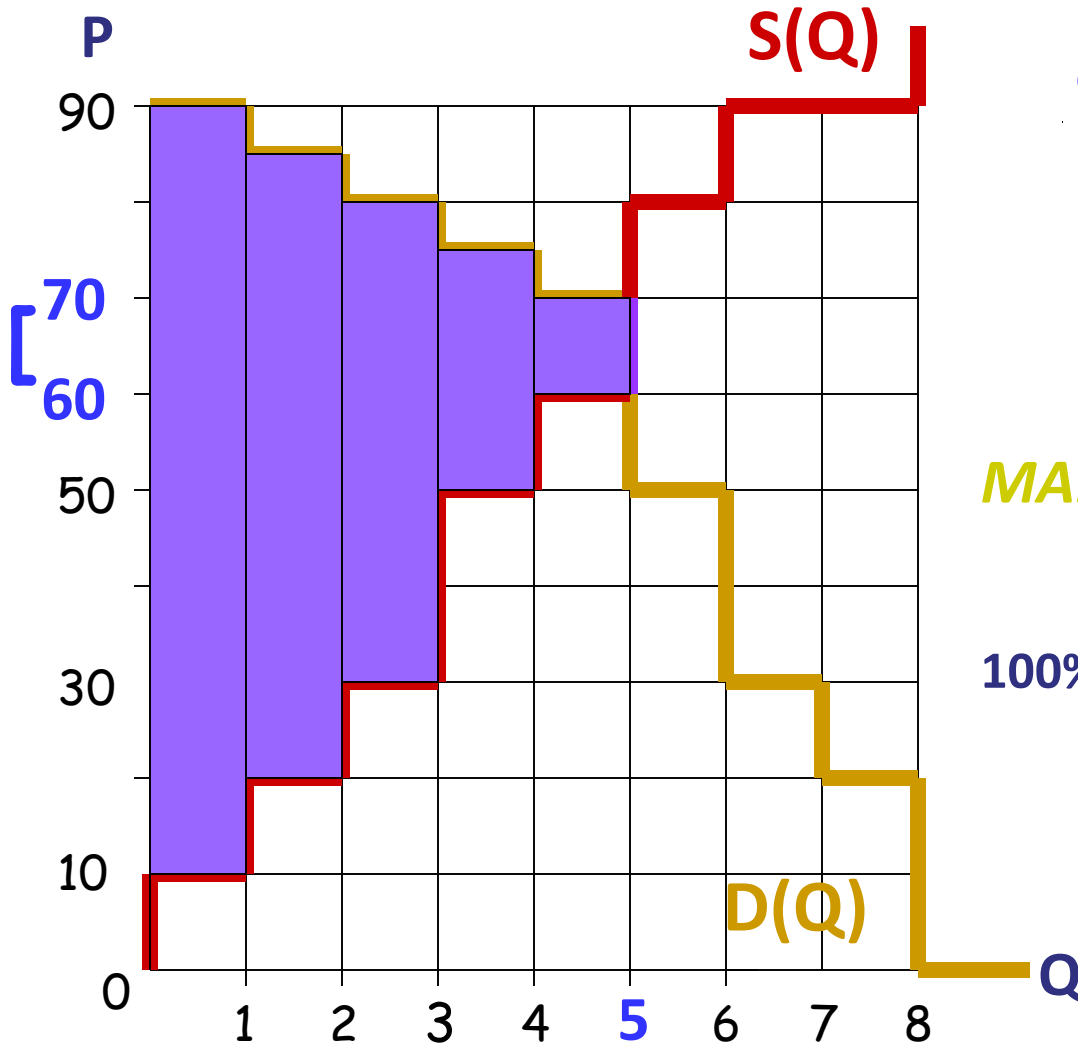
CMC Points:

$Q^*=5, \$60 \leq P^* \leq \70

Bushels Q	MaxBuyP	MinSellP	Net Surplus
1	\$90	- \$10	= \$80
2	\$84	- \$20	= \$64
3	\$80	- \$30	= \$50
4	\$76	- \$50	= \$26
5	\$70	- \$60	= \$10

TOTAL NET SURPLUS: \$230

Standard Measure of Market Efficiency (Non-Wastage of Resources)



CMC Points:

$$Q^*=5, \$60 \leq P^* \leq \$70$$

CMC Total Net Surplus

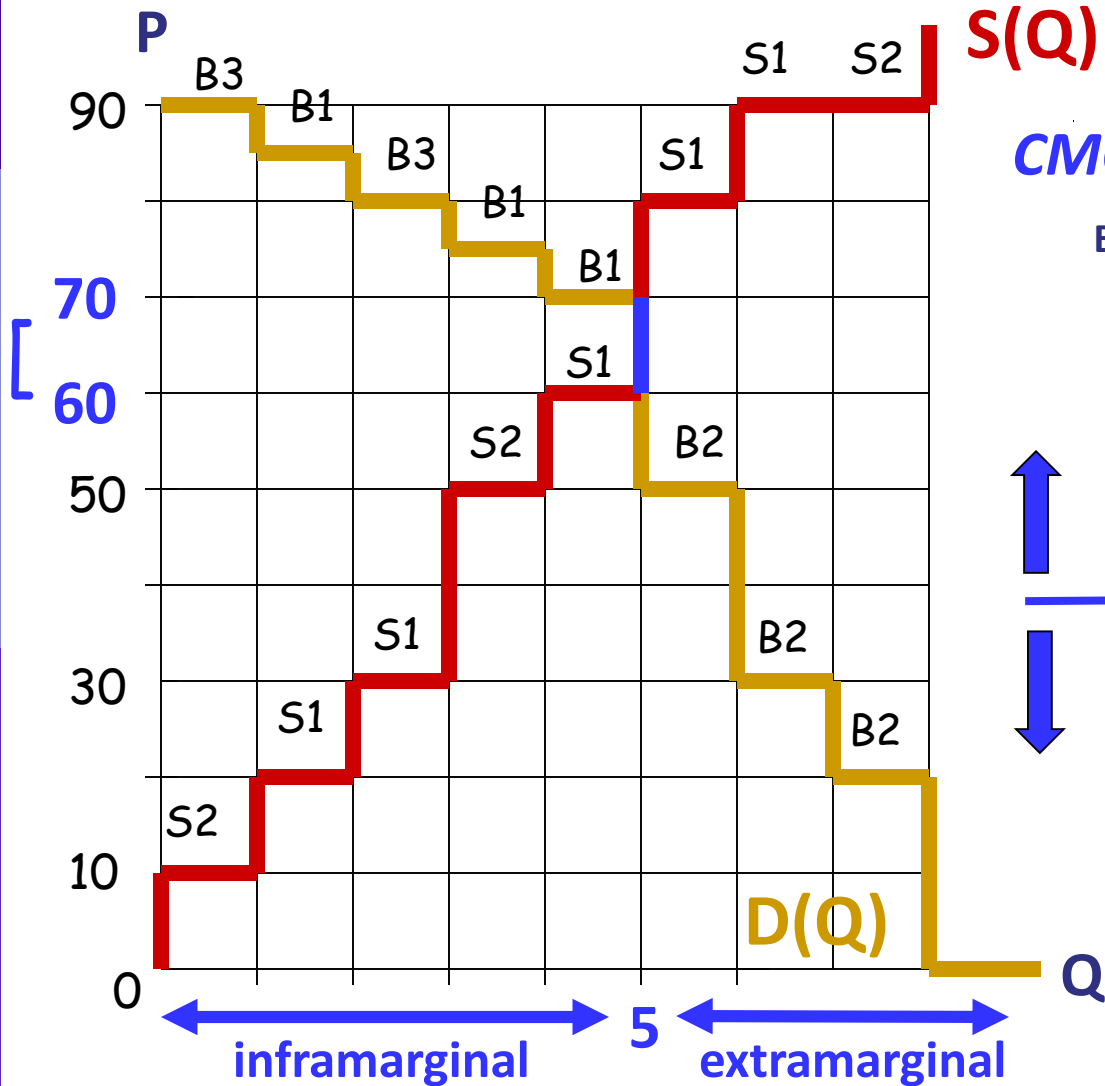
= \$230 (Maximum Possible)

MARKET EFFICIENCY (ME):

$$100\% \times \frac{\text{Extracted Total Net Surplus}}{\text{Max Possible Total Net Surplus}}$$

How can ME be less than 100% ?

Inframarginal vs. Extramarginal Quantity Units at CMC Points



CMC Pts: $Q^*=5, \$60 \leq P^* \leq \70

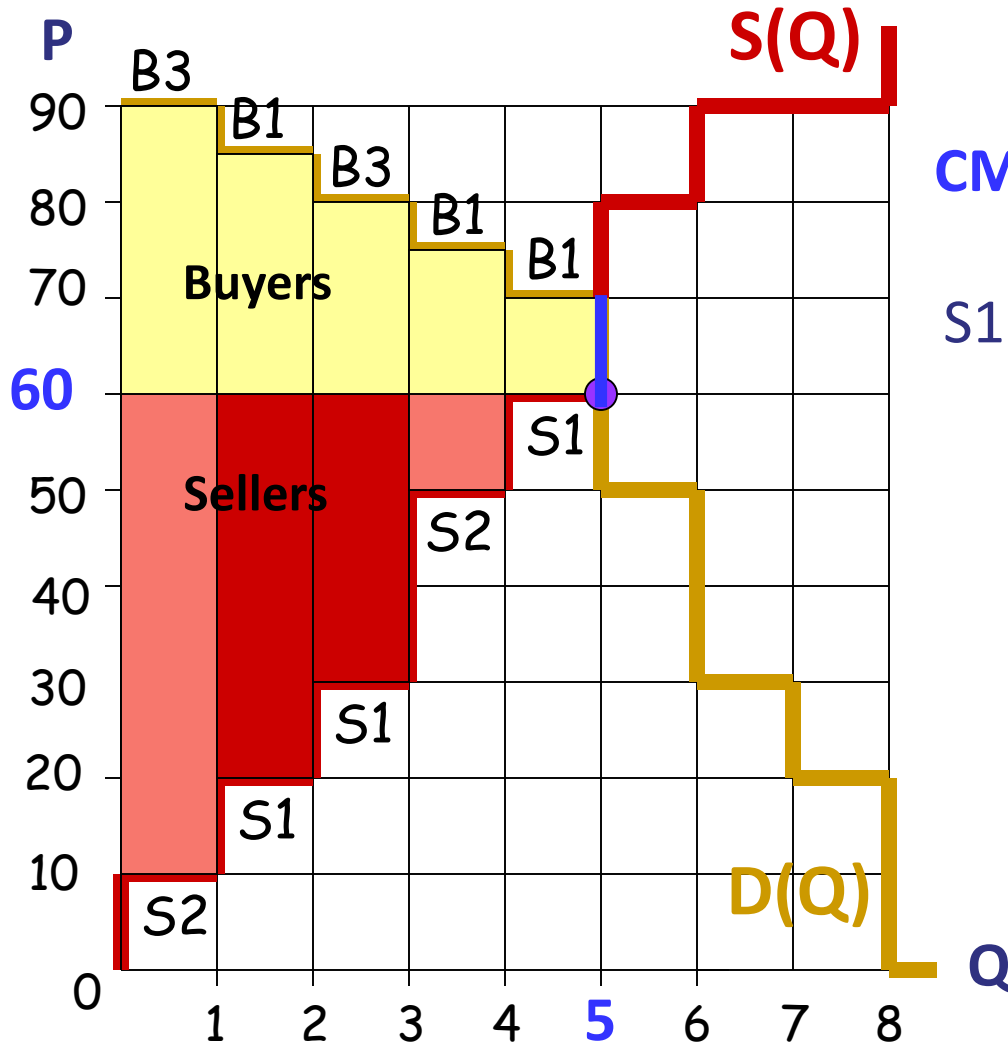
Bushels Q	MaxBuyPrice		MinSellPrice
1	\$90	>	\$10
2	\$84	>	\$20
3	\$80	>	\$30
4	\$76	>	\$50
5	\$70	>	\$60
<hr/>			
6	\$50	<	\$80
7	\$30	<	\$90
8	\$20	<	\$90
9	\$0	<	∞

Market Efficiency < 100% can arise if ...

- ◆ some **inframarginal** quantity unit **fails to trade**
 - E.g., physical capacity withholding (“**market power**”*)
- ◆ some **extramarginal** quantity unit **is traded**
 - a more costly unit is sold in place of a less costly unit (“out-of-merit-order dispatch”)
 - and/or a less valued unit is purchased in place of a more valued unit (“out-of-merit-order purchase”)

* **Market Power:** Ability of a seller or buyer to extract more net surplus from a market than they would achieve at a CMC point.

Example: Exercise of market power by Seller S1 that results in ME < 100%



CMC Point: $Q^*=5$, $P^*=\$60$

S1 Net Surplus at CMC Point:

$$\$60 - \$20 = \$40$$

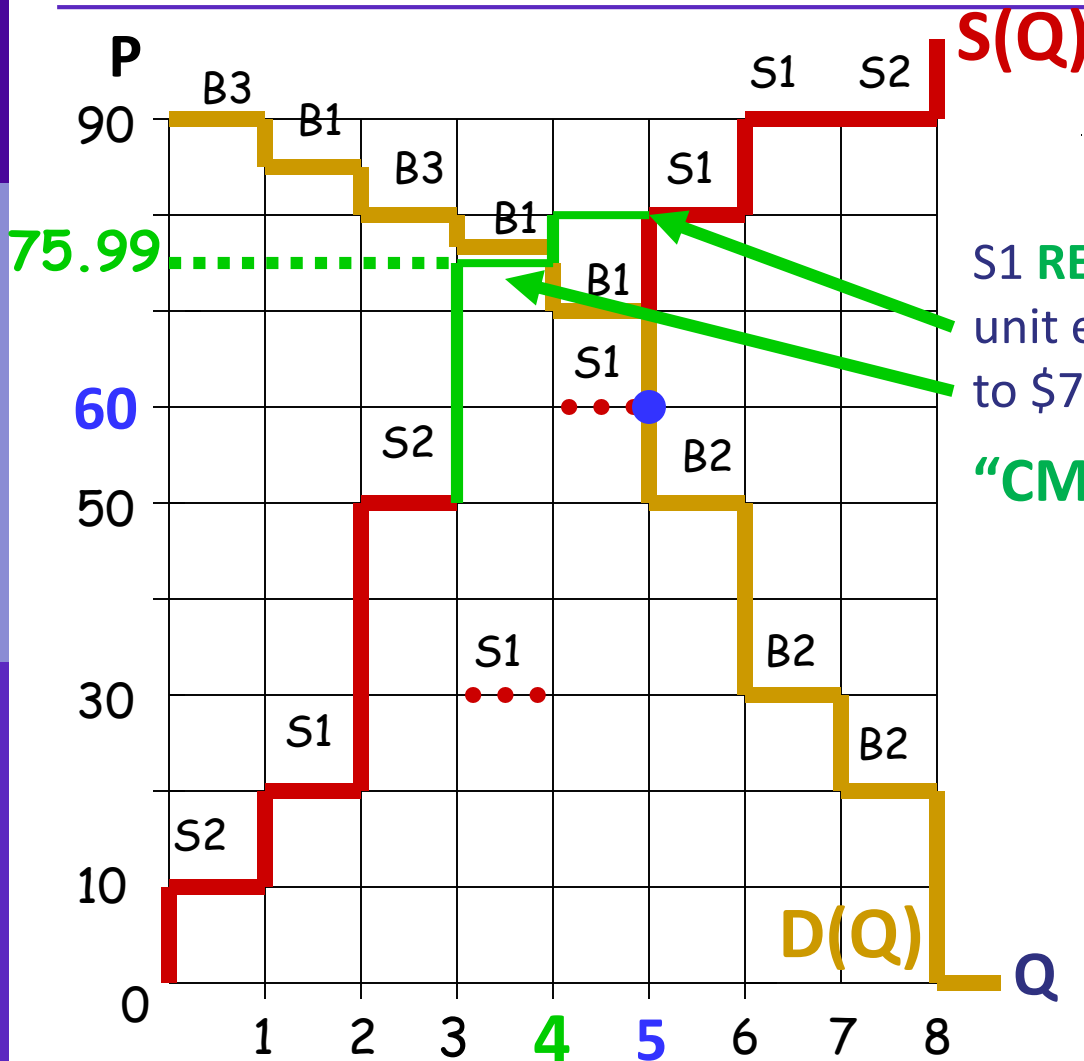
$$\$60 - \$30 = \$30$$

$$\$60 - \$60 = \$0$$

S1 Net Surplus = \$70

Total Net Surplus: \$230

Example: ME < 100% ... Continued



CMC Point: $Q^*=5, P^*=\$60$

$S1$'s CMC Net Surplus = $\$70$

$S1$ **REPORTS** a max sale price on his 3rd unit equal to $\$80$ & on his 2nd unit equal to $\$75.99$.

"CMC" Point: $Q'=4, P' \cong \$76$

At new "CMC" point, $S1$ only sells its first 2 units, but **$S1$'s net surplus increases to $\cong \$102 = [\$56 + \$46]$**

Extracted total net surplus **DECREASES FROM 230 TO 220** because inframarginal 5th unit now fails to sell.

Market Efficiency vs. Social Welfare

- ◆ **Efficiency** for one market at one time point is a very narrow measure of resource non-wastage.
- ◆ Ideally, **social** efficiency should be measured by resource non-wastage across **all** markets and across **all** current and future time periods.
- ◆ Moreover, economists measure **social welfare** in terms of the **“utility” (well-being) of people** in their roles as consumers/users of final goods and services.
- ◆ **Social efficiency** is **necessary but not sufficient** for the optimization of **social welfare**.

Market Efficiency, Social Welfare, and the Extraction of Net Surplus by “Third Parties”

- ◆ Suppose [price P_S paid to a seller] < [price P_B charged to a buyer] for some quantity unit sold in a market

➔ **Net surplus $[P_B - P_S]$ is extracted by some type of “third party”**

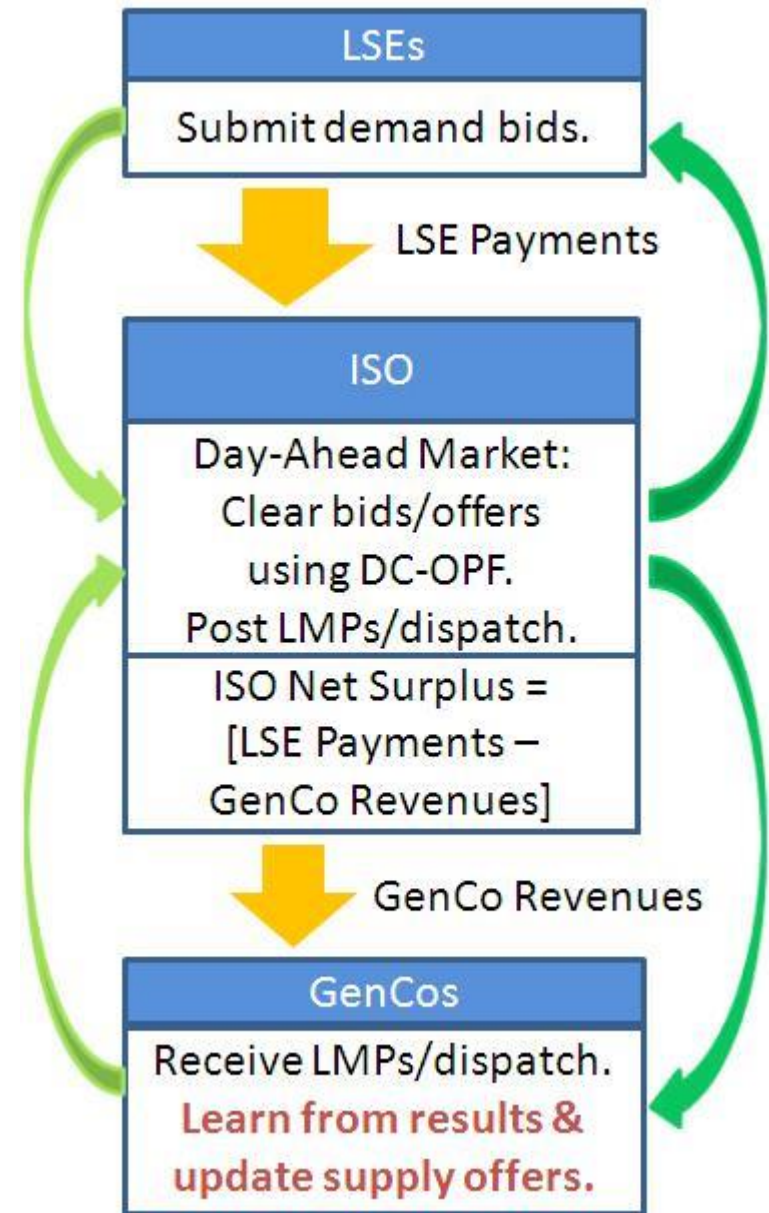
Examples: Gov't tax revenues; ISO net surplus extractions that result from grid congestion in **Day-Ahead Markets (DAMs)** for grid-delivered energy (MWh) settled by means of **Locational Marginal Prices LMP(b,H)** (\$/MWh) conditional on grid delivery location b and operating hour H .

- ◆ “First order effect” of this **third-party extracted net surplus** is a decrease in the net surplus going to sellers & buyers.
- ◆ **Social efficiency/welfare implications** of this third-part extracted net surplus depend on precisely how it is extracted and to what uses it is subsequently put.

Discussion of double auctions, market efficiency, & social welfare specialized to an ISO managed **Day-Ahead Market (DAM)** for grid-delivered energy (MWh) with LMP settlements (\$/MWh):

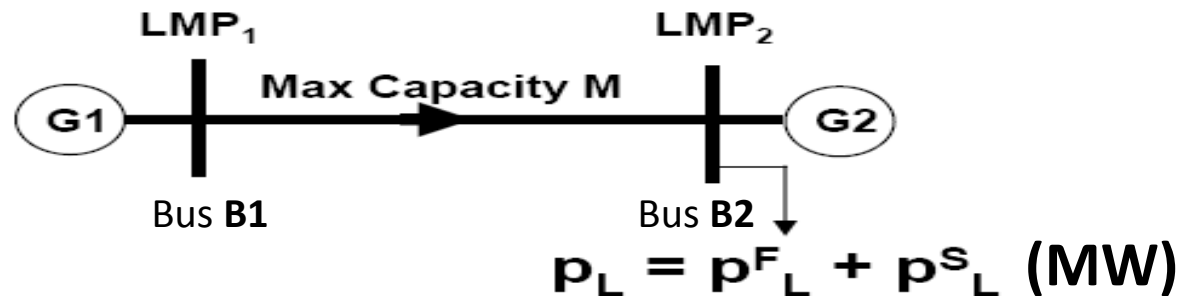


Day-ahead market activities on a typical operating day D:



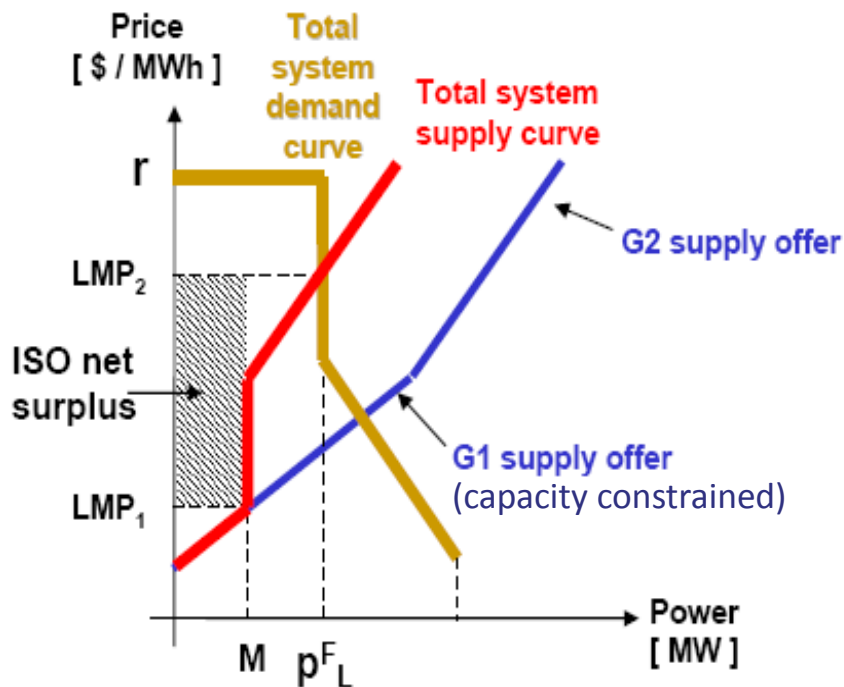
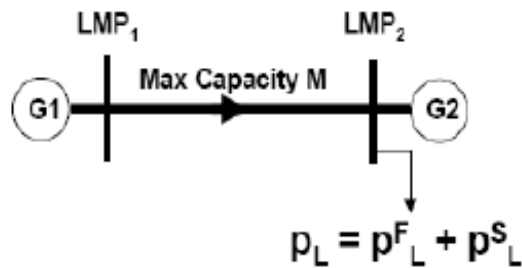
ISO Net Surplus Extraction: DAM Example

(adapted from H. Salazar, MS Thesis, Nov 2008)



- A **Day-Ahead Market (DAM)** is held on day **D** for an operating hour **H** on day **D+1**
- The transacted good is grid-delivered energy (MWh), expressed in terms of power levels p (MW) to be maintained during hour **H** (1h)
- **G1, G2** = Generation Companies (GenCos) located at grid buses **B1** and **B2**
- p_L = Total demand (MW) of a **Load-Serving Entity (LSE)** at bus **B2** for hour **H**
- p_L^F = Fixed (i.e., not price sensitive) demand (MW) of **LSE** at bus **B2** for hour **H**
- p_L^S = Price-sensitive demand (MW) of **LSE** at bus **B2** for hour **H**
- LMP_1 = Locational Marginal Price (\$/MWh) at bus **B1** for hour **H**
- LMP_2 = Locational Marginal Price (\$/MWh) at bus **B2** for hour **H**
- r = Regulated rate (\$/MWh) for **LSE** retail resale of fixed demand for hour **H**

ISO Net Surplus Example ... Continued



Cleared load = p_L^F . LSE at bus 2 pays $LMP_2 > LMP_1$ for each unit of p_L^F . M units of p_L^F are supplied by cheaper G1 at bus 1 who receives only LMP_1 per unit.

ISO collects payment difference:

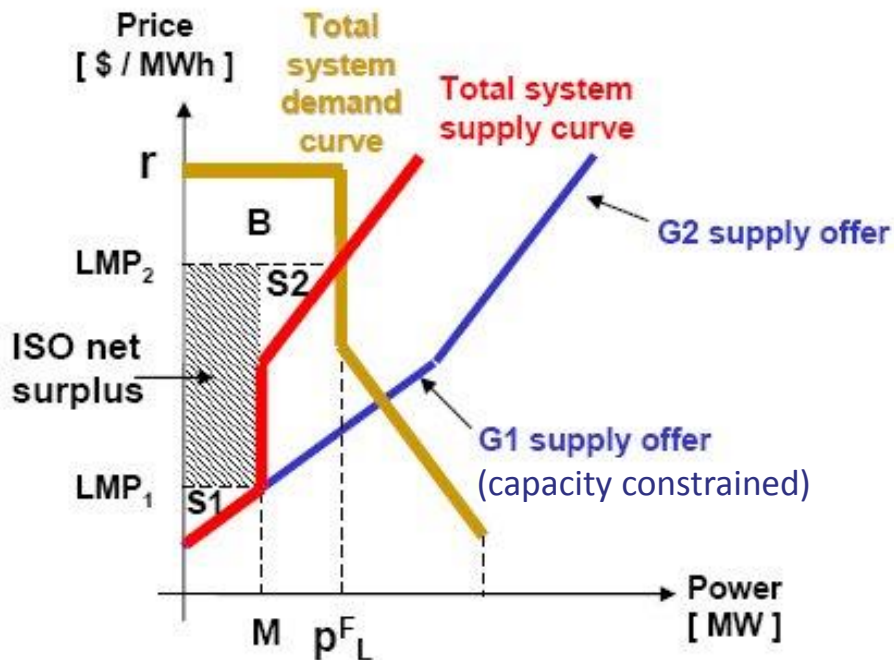
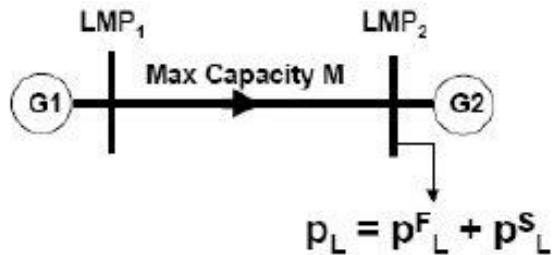
ISO Net Surplus

$$= [\text{LSE Payments} - \text{GenCo Revenues}]$$

$$= M \times [LMP_2 - LMP_1]$$

Note: The capacity limit M is binding in this example. Otherwise, $LMP_1 = LMP_2 = \text{CMC Point!}$

ISO Net Surplus Example ... Continued



ISO Net Surplus:

$$INS = M \times [LMP_2 - LMP_1]$$

GenCo Net Surplus:

$$GNS = \text{Area S1} + \text{Area S2}$$

LSE Net Surplus:

$$LNS = \text{Area B}$$

Total Net Surplus:

$$TNS = [INS + GNS + LNS]$$

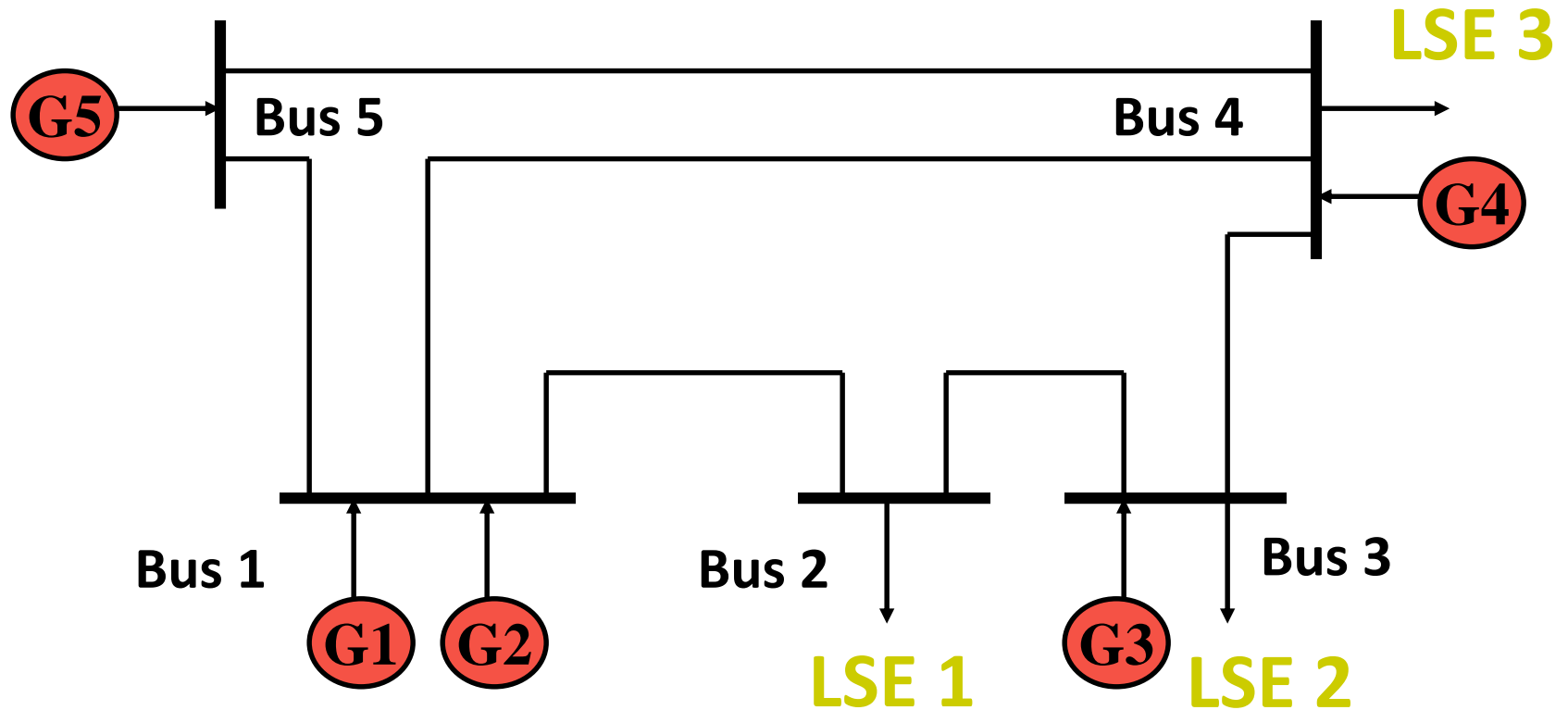
ISO Objective (Optimal Power Flow):

Maximize **TNS** subject to transmission & generation constraints.

ISO Net Surplus Experiments (Li/Tesfatsion, 2009)

(Experiments run with AMES Wholesale Power Market Test Bed)

Five GenCo sellers G1,...,G5 and three LSE buyers LSE 1, LSE 2, LSE 3

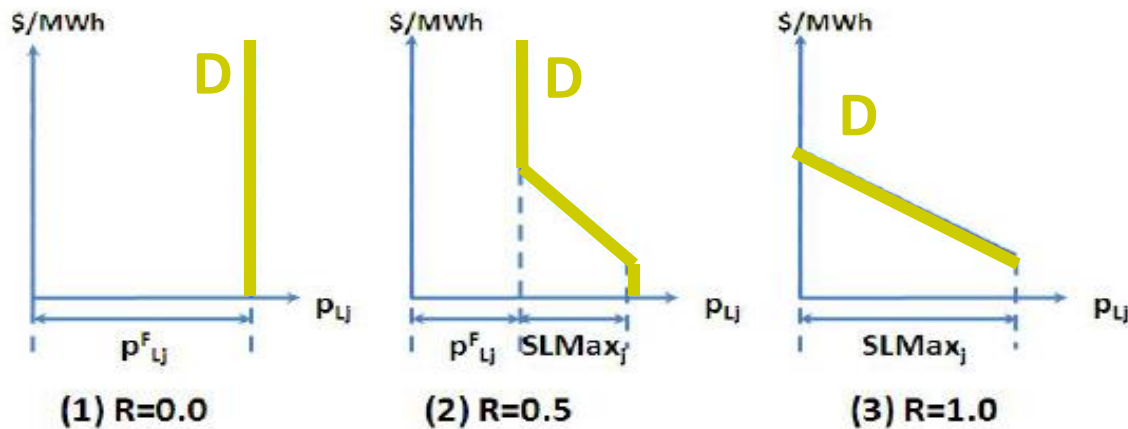


Experimental Outcomes: Varied Price-Sensitivity for Demand Bids

Demand bid for LSE j (MW):

Fixed demand bid p_{Lj}^F + Price-sensitive demand bid p_{Lj}^S ,

where $0 \leq p_{Lj}^S \leq SLMax_j$



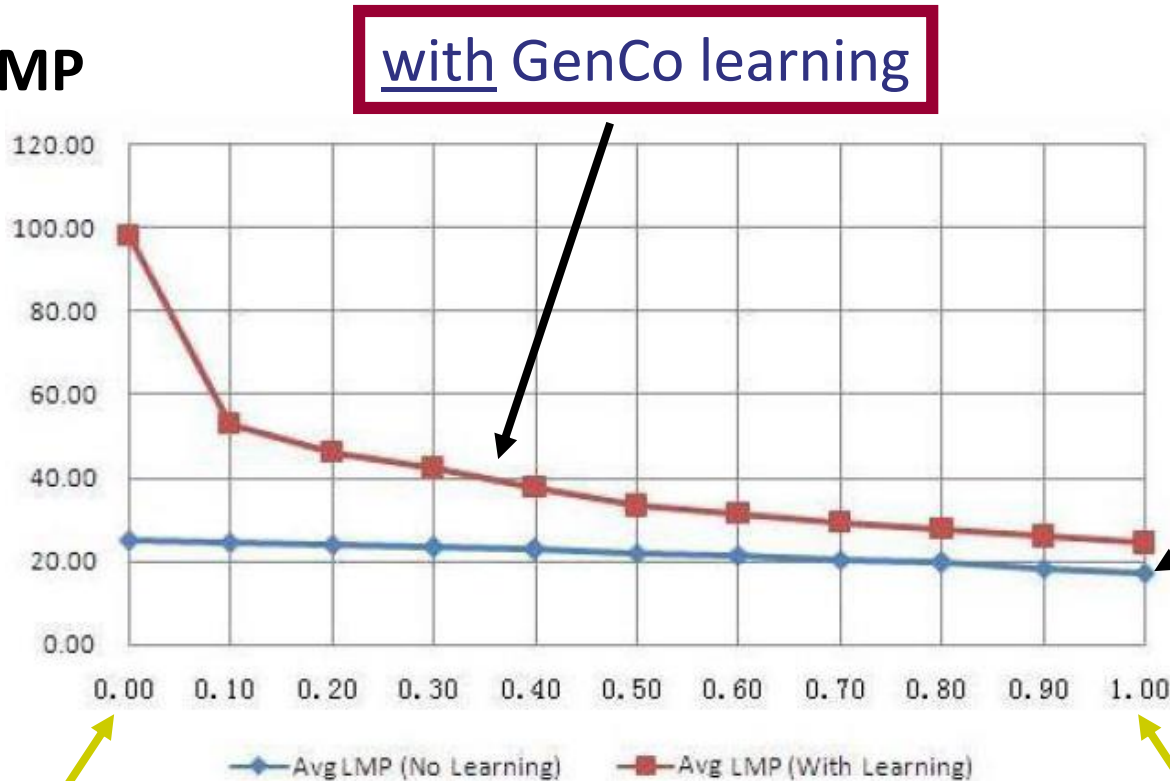
100% fixed demand

100% price-sensitive demand

Average LMP Outcomes on Day 1000

(under varied **GenCo learning** & **LSE demand price-sensitivity** treatments)

Avg LMP

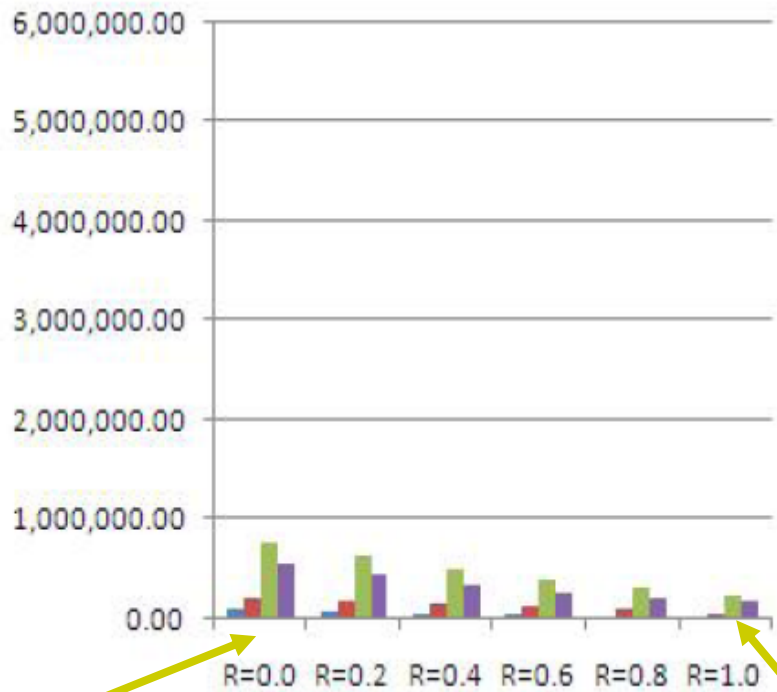


LSE demand is 100% fixed

LSE demand is 100% price sensitive

Average ISO Net Surplus Outcomes on Day 1000 for varied learning & demand treatments

Without Learning

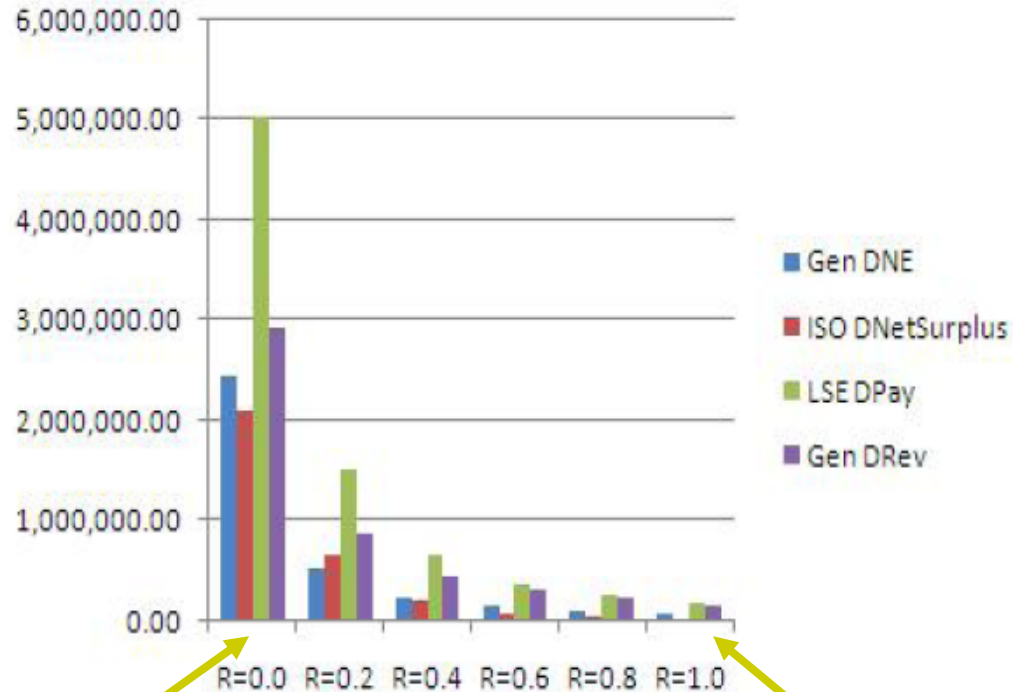


100% fixed

100% price sensitive

■ = GenCo Net Earnings

With Learning GenCos



100% fixed

100% price sensitive

■ = ISO Net Surplus

ISO Net Surplus, Market Efficiency, and Social Welfare

- ◆ Two-bus example and experimental findings suggest ISO net surplus extractions can be **substantial**, and can **dramatically increase** with:
 - *decreases* in price sensitivity of demand
 - *increases* in GenCo learning ability resulting in the reporting of supply offers at higher-than-true costs (especially profitable in presence of fixed demand)
- ◆ **Important Issue:** How to ensure ISO financial incentives are properly aligned with goal of ensuring market efficiency/soc welfare?

Conclusion

- ❑ Day-ahead energy markets for restructured wholesale power markets are currently organized as Double Auctions (DAs)
- ❑ Standard DA theory does not consider the efficiency/welfare implications of net surplus extractions by third parties, *in particular the extractions by auction managers (e.g. by ISOs).*
- ❑ ISO net surplus extraction increases in circumstances that are unfavorable to market efficiency (hence to social welfare).
- ❑ Transparent reporting & oversight of ISO operations are essential because traditional ISO reliability objectives are not fully aligned with social efficiency/welfare objectives.

On-Line Resources

(Updated 2011)

- ❑ L. Tesfatsion (2009), **“Auction Basics for Wholesale Power Markets: Objectives & Pricing Rules,”** *IEEE PES General Meeting Proceedings*, July.
<https://www2.econ.iastate.edu/tesfatsi/AuctionTalk.LT.pdf> (Slide-Set)
<https://www2.econ.iastate.edu/tesfatsi/AuctionBasics.IEEEPES2009.LT.pdf> (Paper)

- ❑ H. Li & L. Tesfatsion (2011), **“ISO Net Surplus Collection and Allocation in Wholesale Power Markets Under Locational Marginal Pricing,”** *IEEE Transactions on Power Systems*, Vol. 26, No. 2, pp 627-641.
<https://www2.econ.iastate.edu/tesfatsi/ISONetSurplus.WP09015.pdf>

- ❑ **AMES Test Bed Homepage** (Code/Manuals/Publications)
<https://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm>