Auction Basics for Wholesale Power Markets: Objectives and Pricing Rules

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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

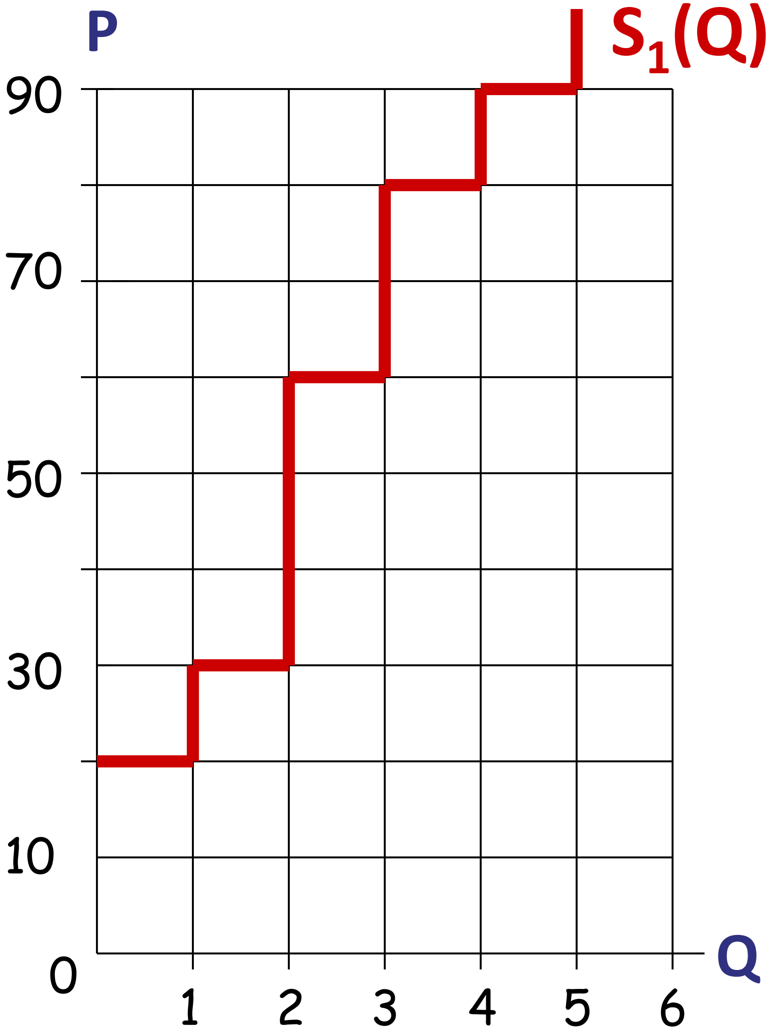
- In many regions of U.S., wholesale electric energy -- measured in megawatt-hours (MWh) -- is transacted in "day-ahead" markets designed as double auctions.

- ***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 = Price and Q = Quantity



Q = **Quantity** of specialty apples (in bushels)
P = **Price** of specialty apples ($ per bushel)

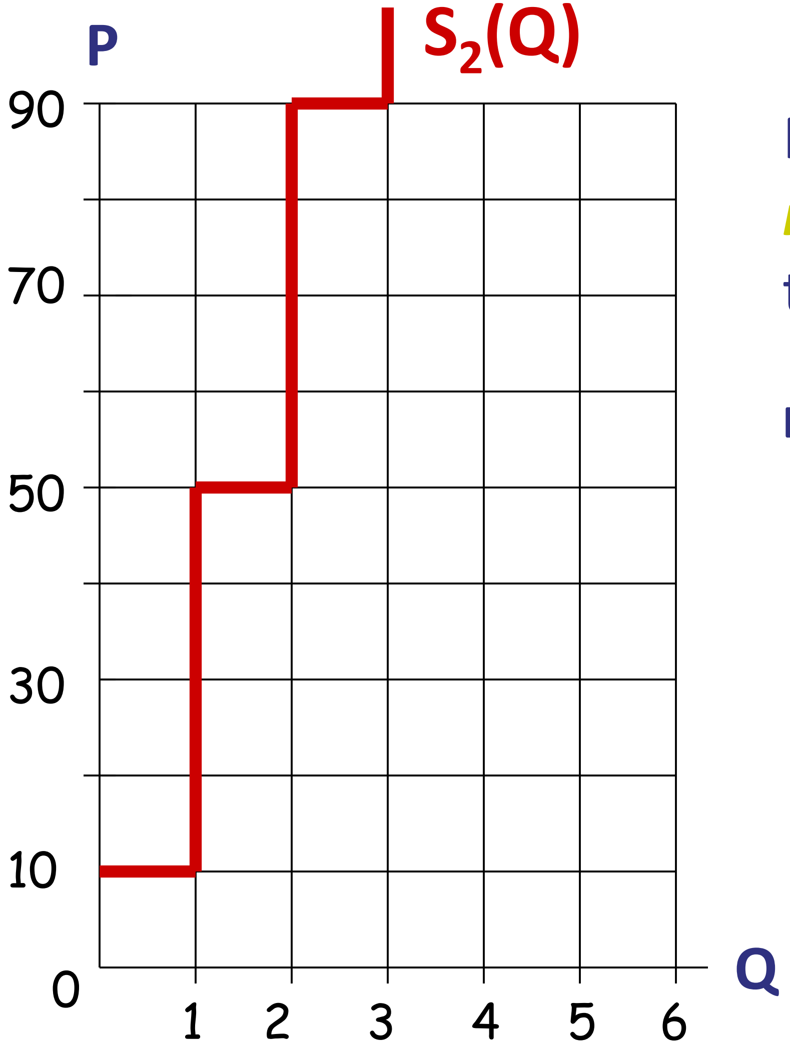
For each Q: $P=S_1(Q)$ is Seller 1's ***minimum acceptable sale price*** for the "last" bushel it supplies at Q.

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 = Price and Q = Quantity

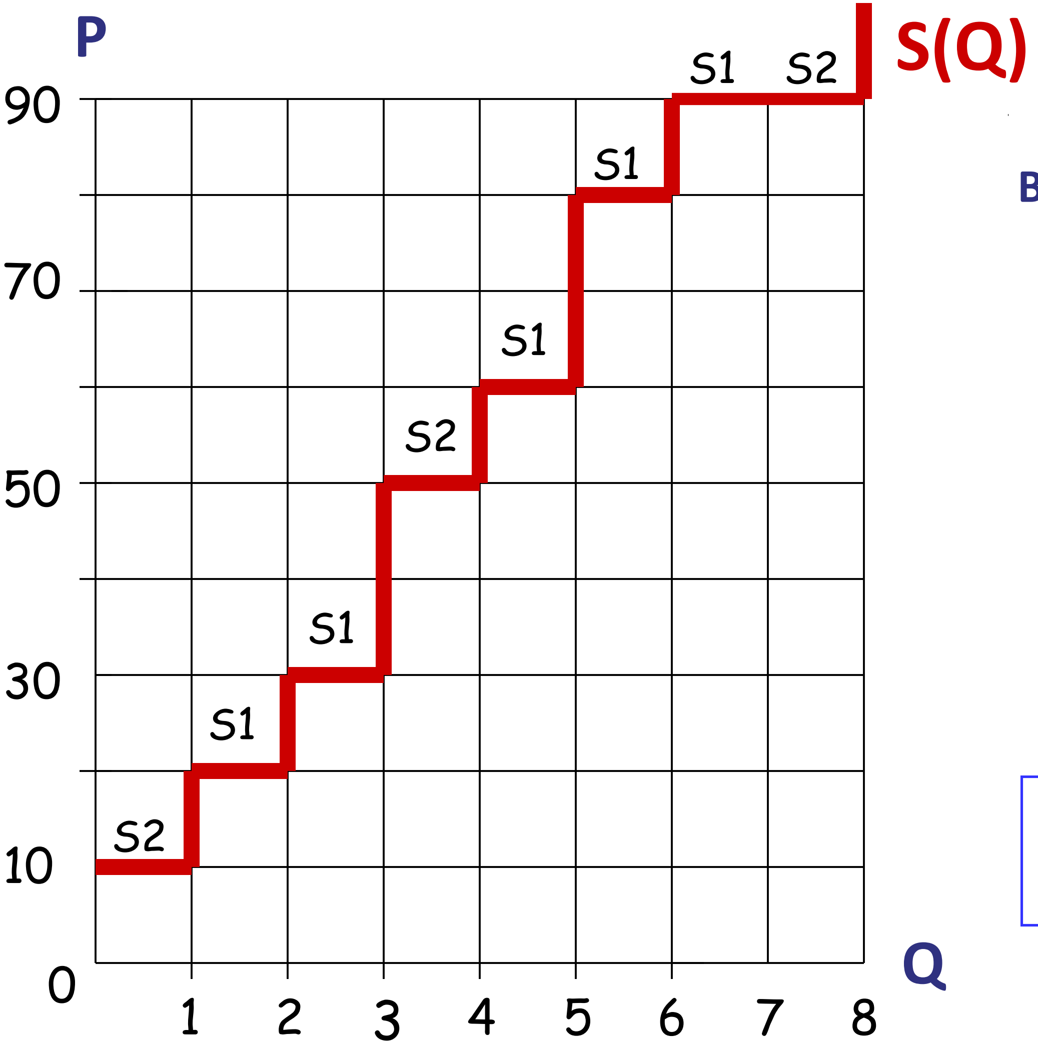


For each Q: P = $S_2(Q)$ is Seller 2's ***minimum acceptable sale price*** for the last bushel it supplies at Q.

Bushels Q	Price P = $S_2(Q)$
1	\$10
2	\$50
3	\$90
4	∞

3 bushels = Seller S_2's max possible supply.

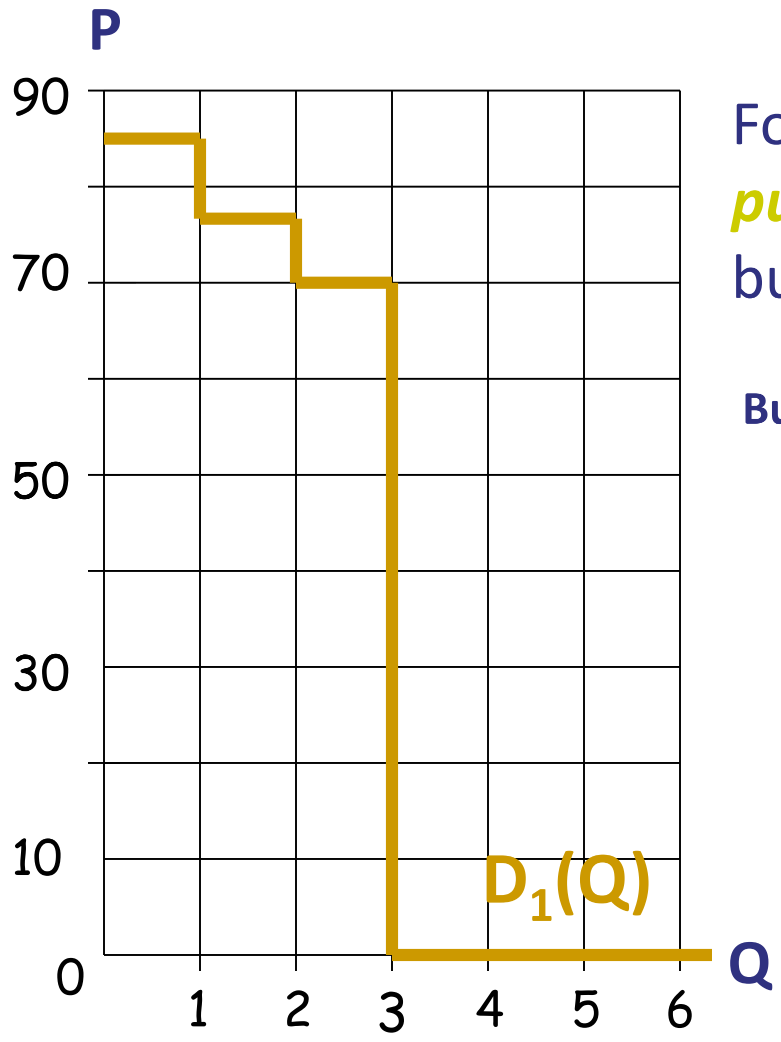
Total System (Inverse) Supply Function: P = S(Q)



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 <u>total</u> market supply
= 8 bushels of apples.

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



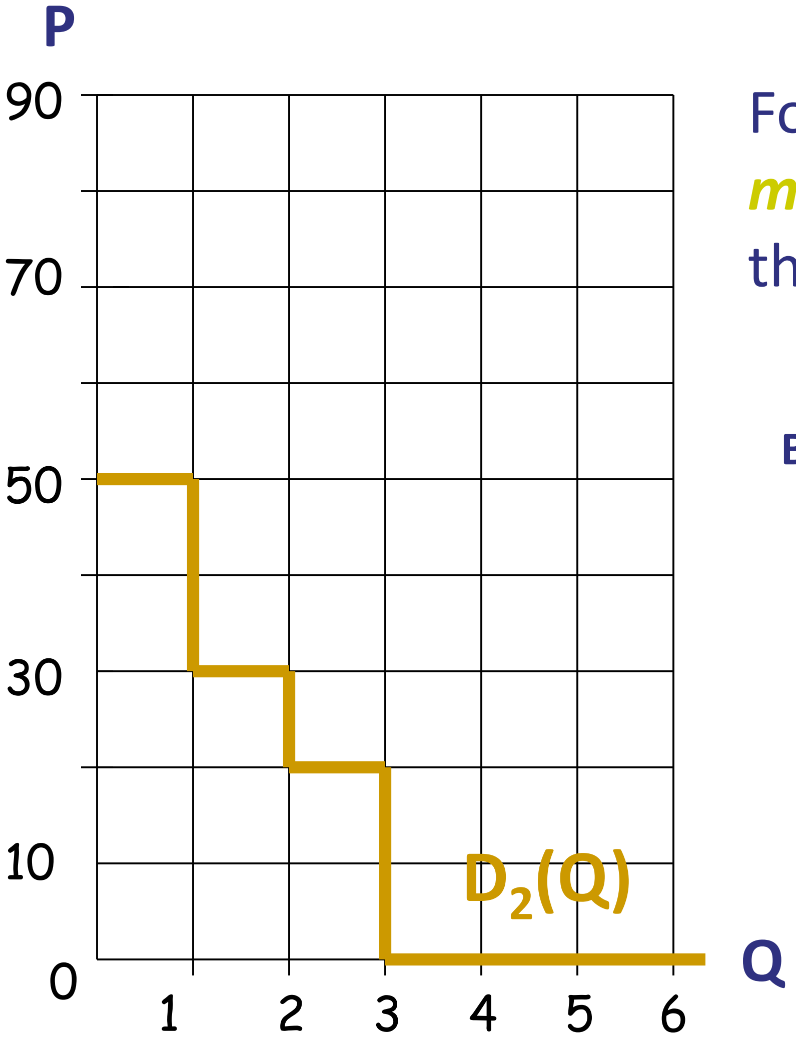
For each Q: P = $D_1(Q)$ is Buyer 1's ***max purchase price*** (\$/bushel) for the last bushel it purchases at Q.

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"*** ≡ ***"maximum willingness to pay"*** is also called a ***"(purchase) reservation value."***

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

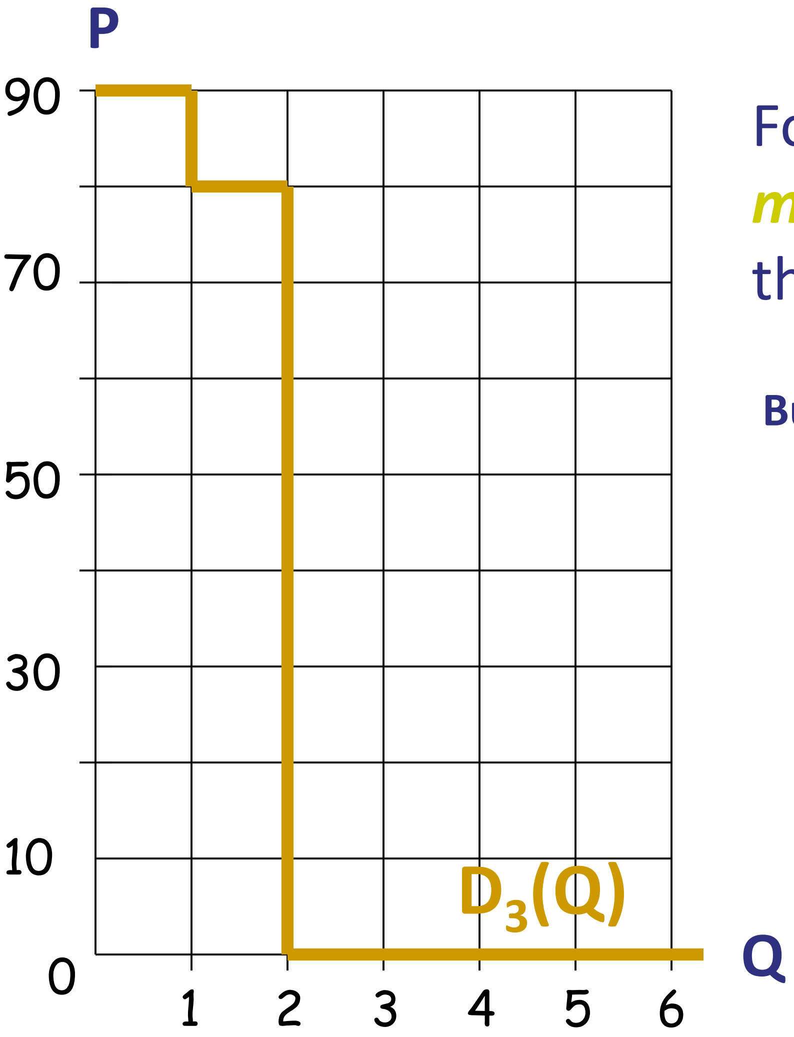


For each Q: $P = D_2(Q)$ is Buyer 2's ***max purchase price*** ($/bushel) for the last bushel it purchases at Q.

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

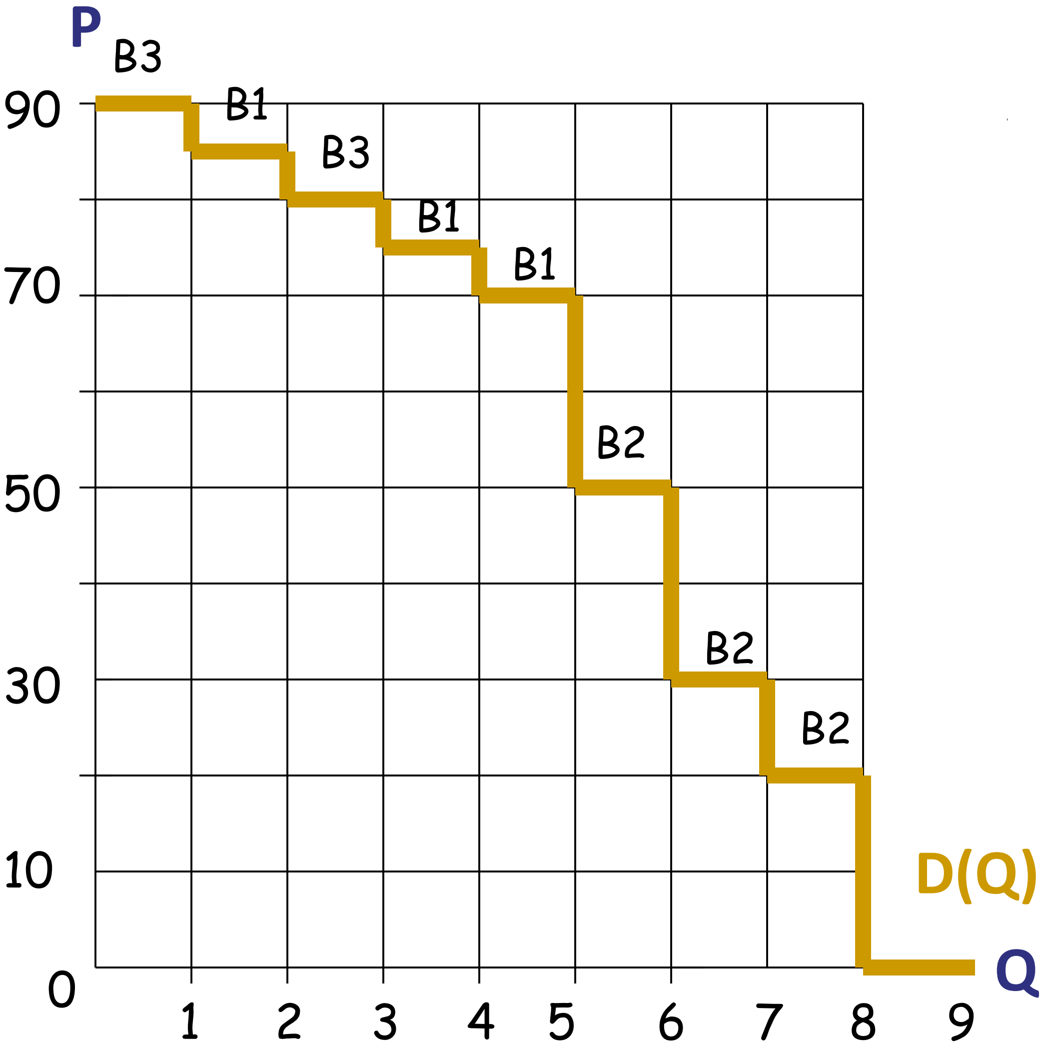


For each Q: P = $D_3(Q)$ is Buyer 3's *max purchase price* ($/bushel) for the last bushel it purchases at Q

Bushels Q	**Price P = $D_3(Q)$**
1	$90
2	$80
3	$ 0

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

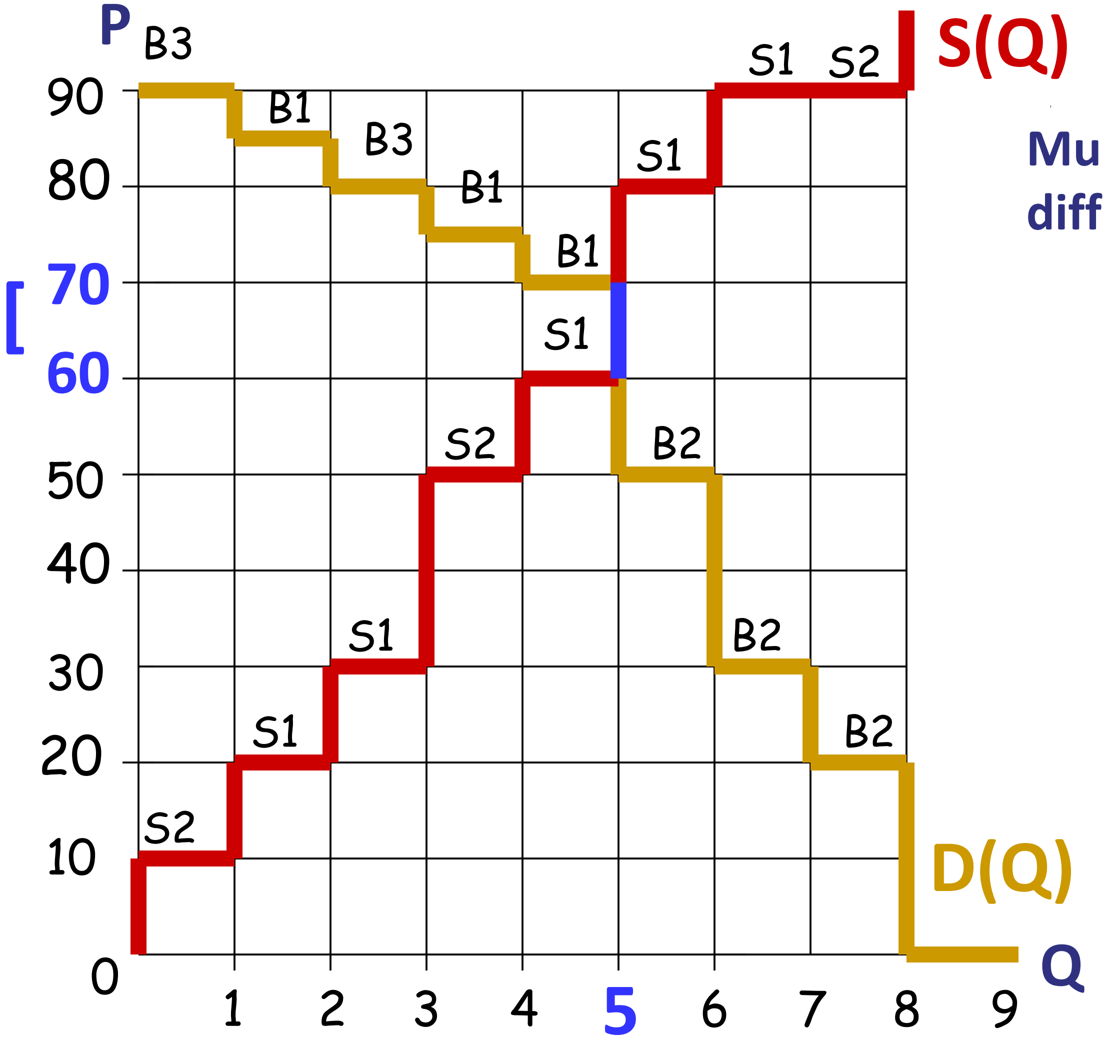
Total System (Inverse) Demand Function: P = D(Q)



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)



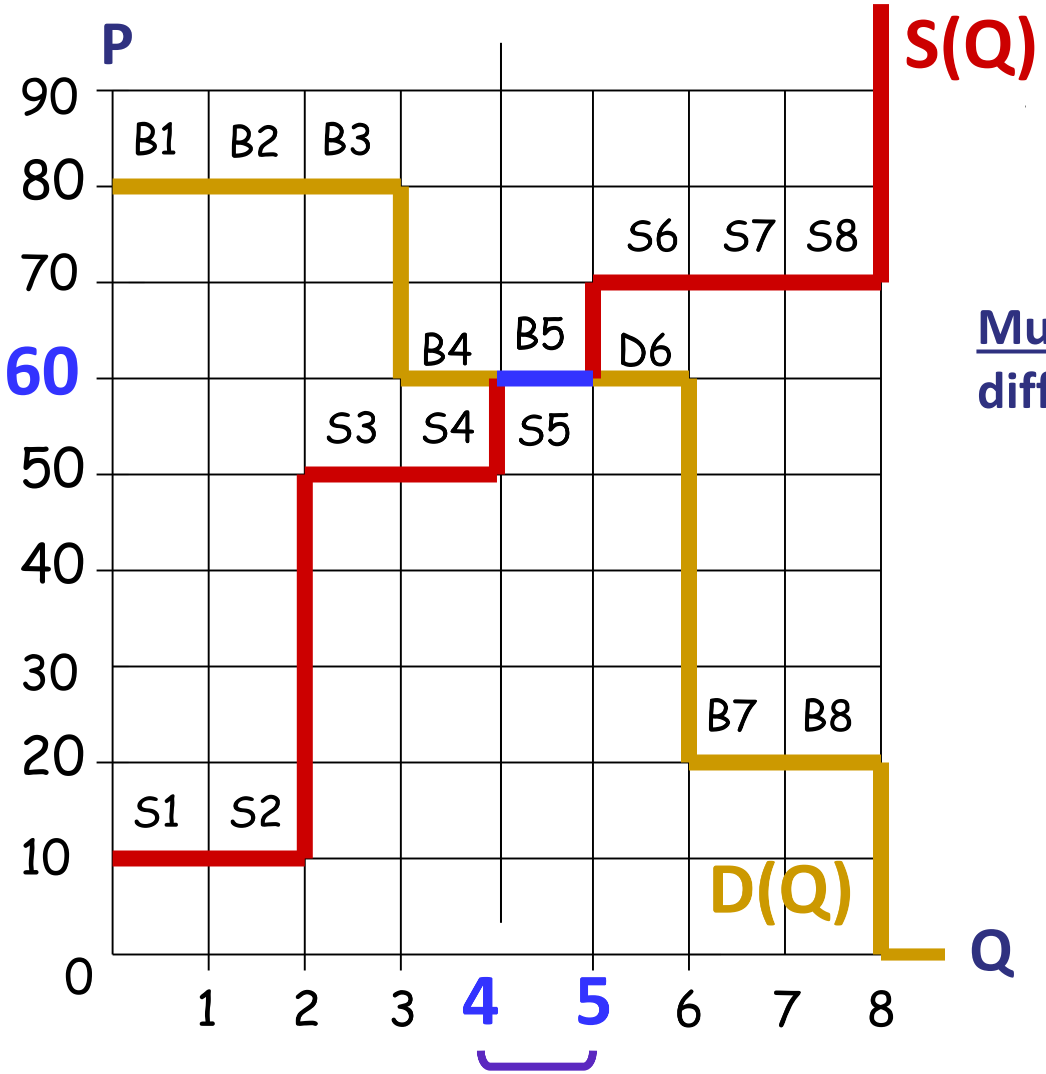
Multiple CMC points (Q*,P*) with different CMC <u>prices</u> P*:

Q*=5, $60 ≤ P*≤ $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 !

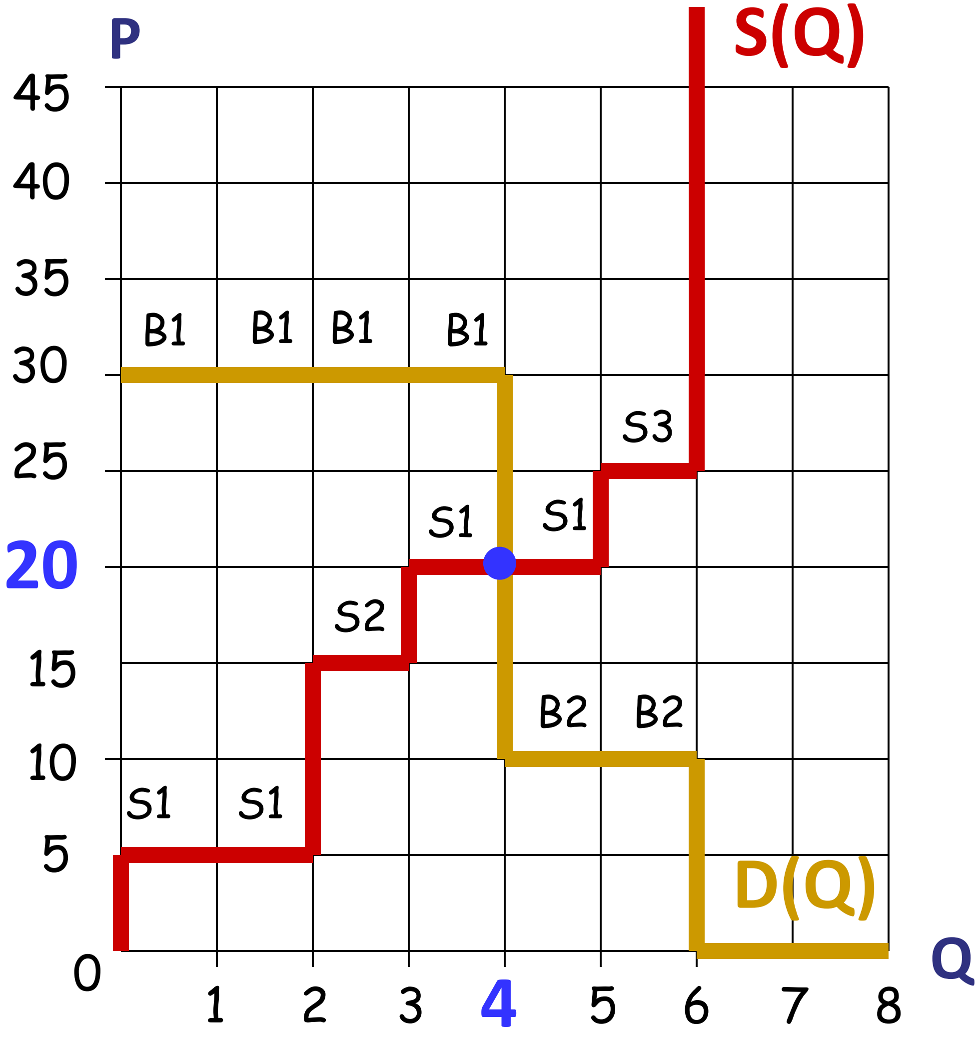
Can also possibly have multiple CMC points with a range of CMC quantities



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

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

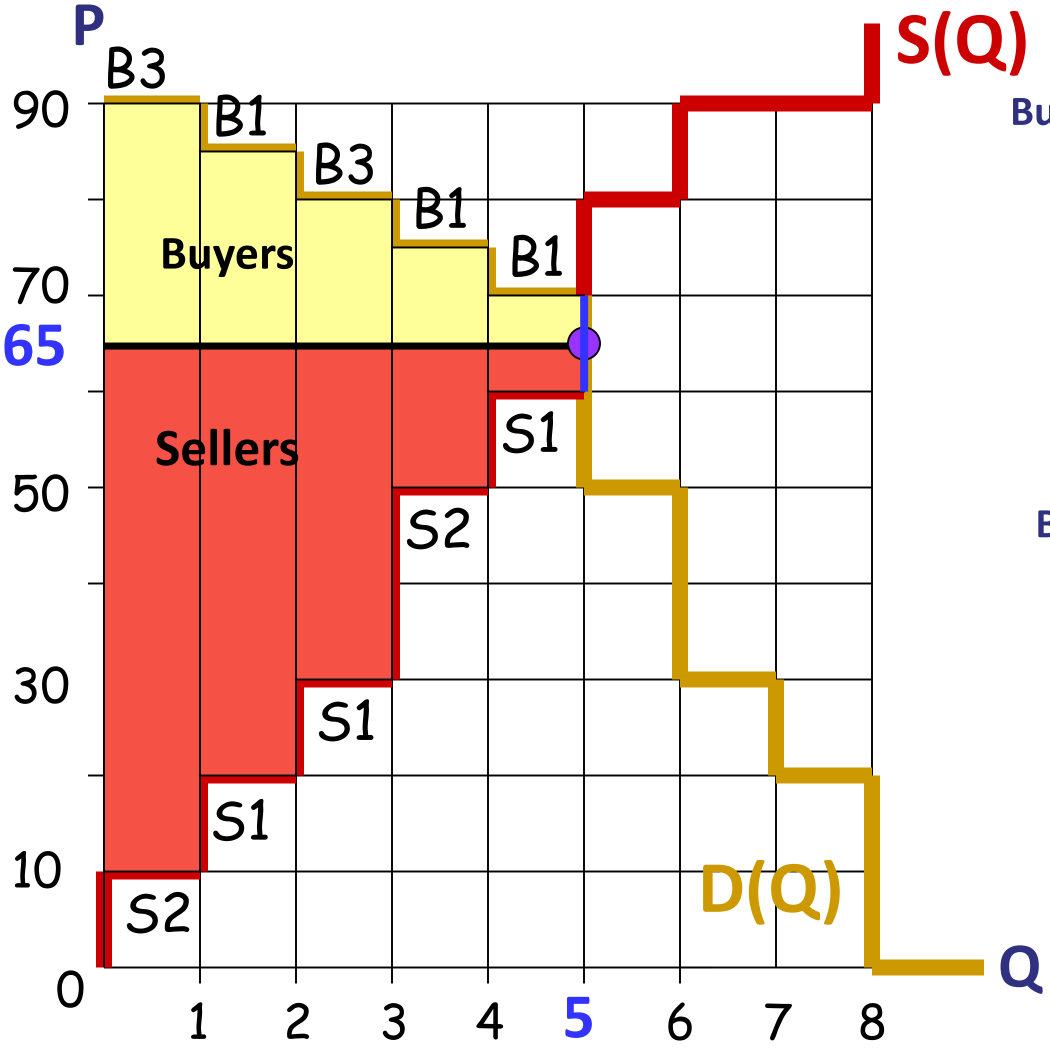
Can also possibly have a unique CMC point



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

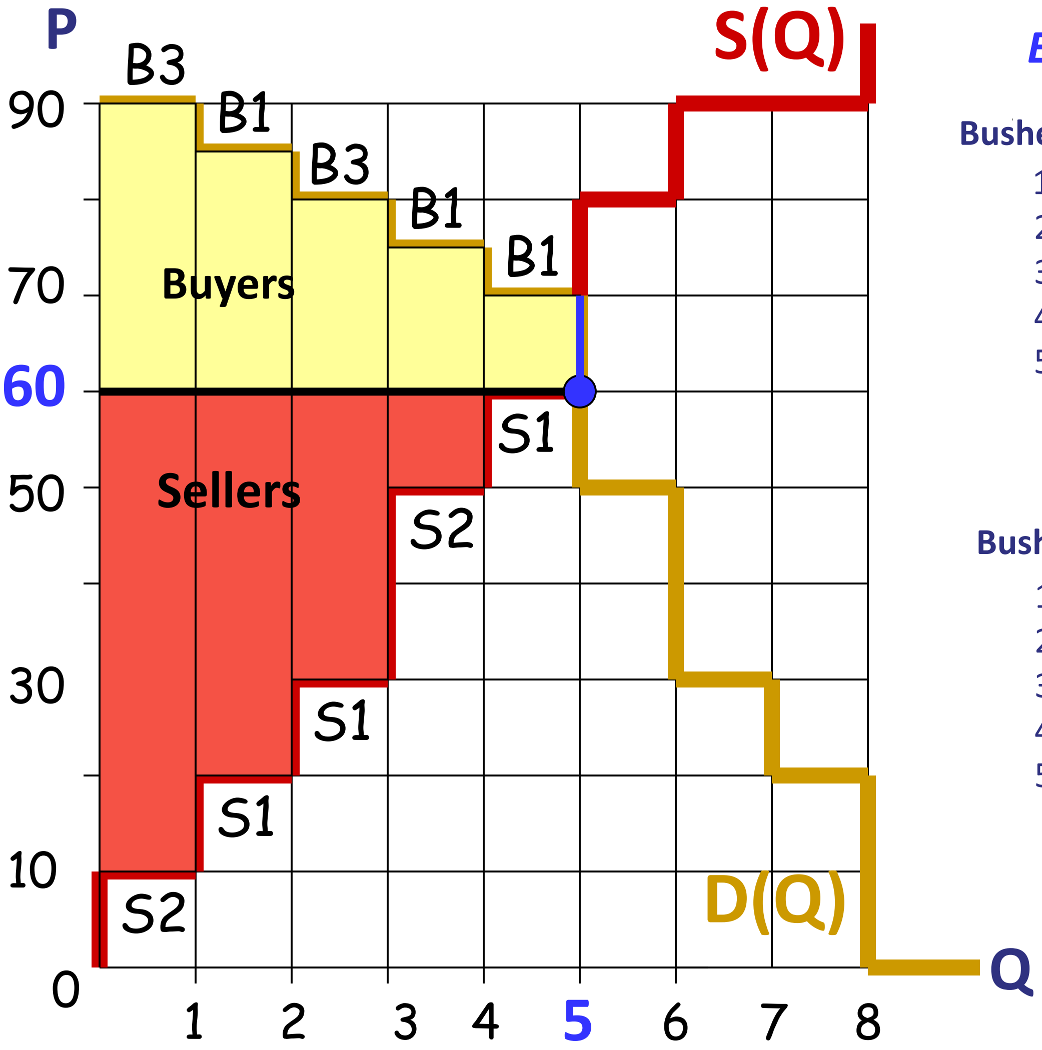
BUYER NET SURPLUS: $75

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

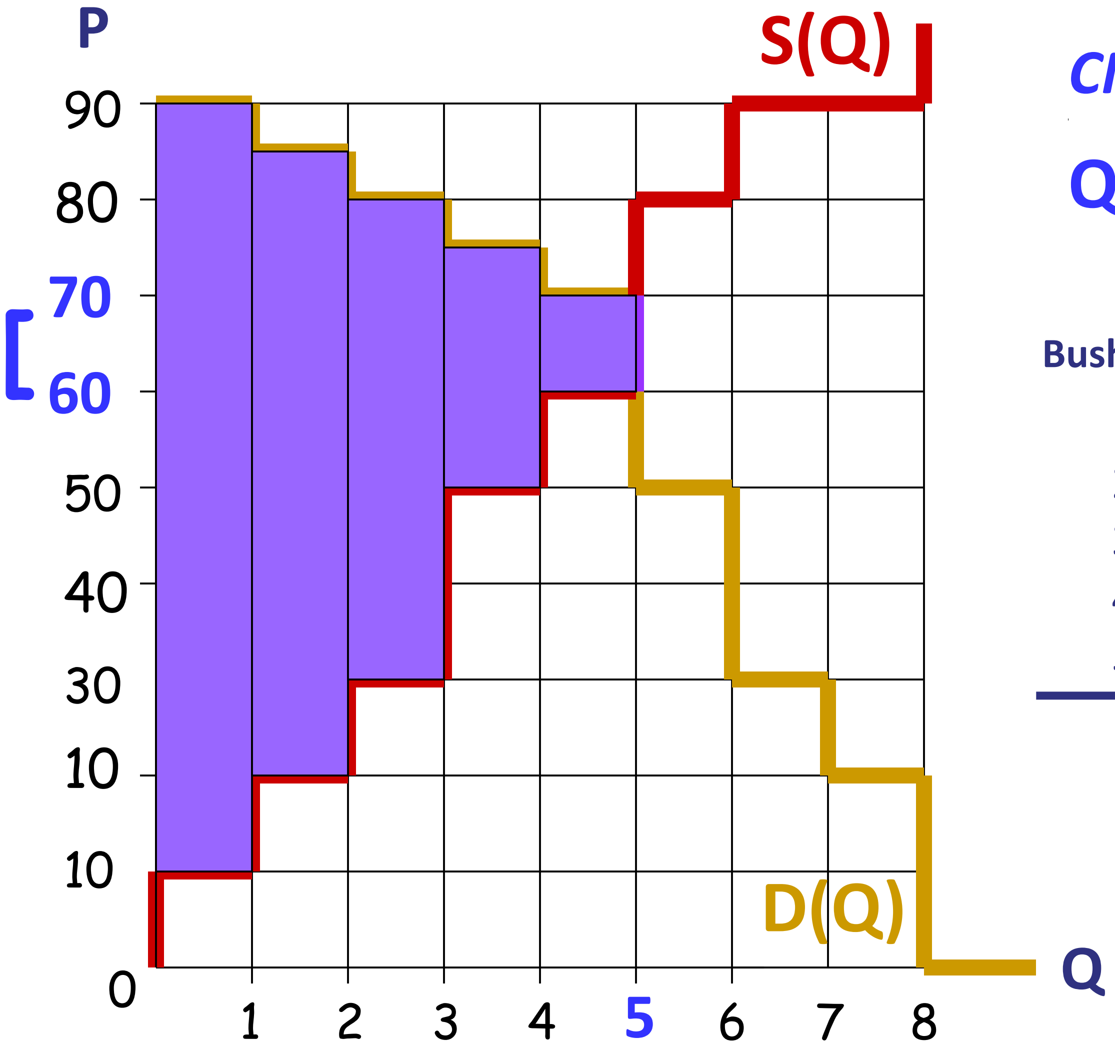
Bushels Q	P*=65		MinSellPrice		SellNetSurplus
1	$60	-	$10	=	$50
2	$60	-	$20	=	$40
3	$60	-	$30	=	$30
4	$60	-	$50	=	$10
5	$60	-	$60	=	$ 0

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:

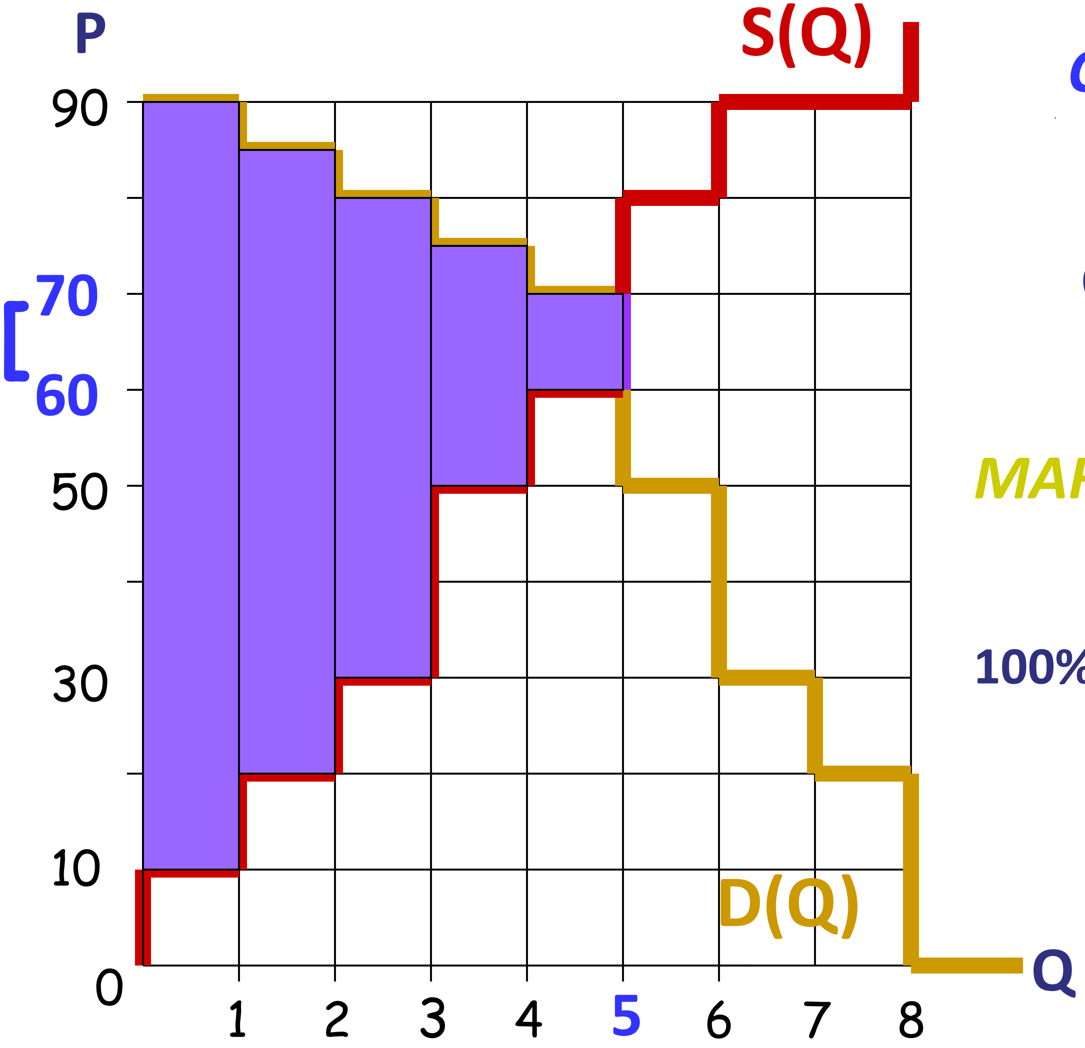
Q*=5, \$60 ≤ P*≤ \$70

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 ≤ P*≤ $70

CMC Total Net Surplus

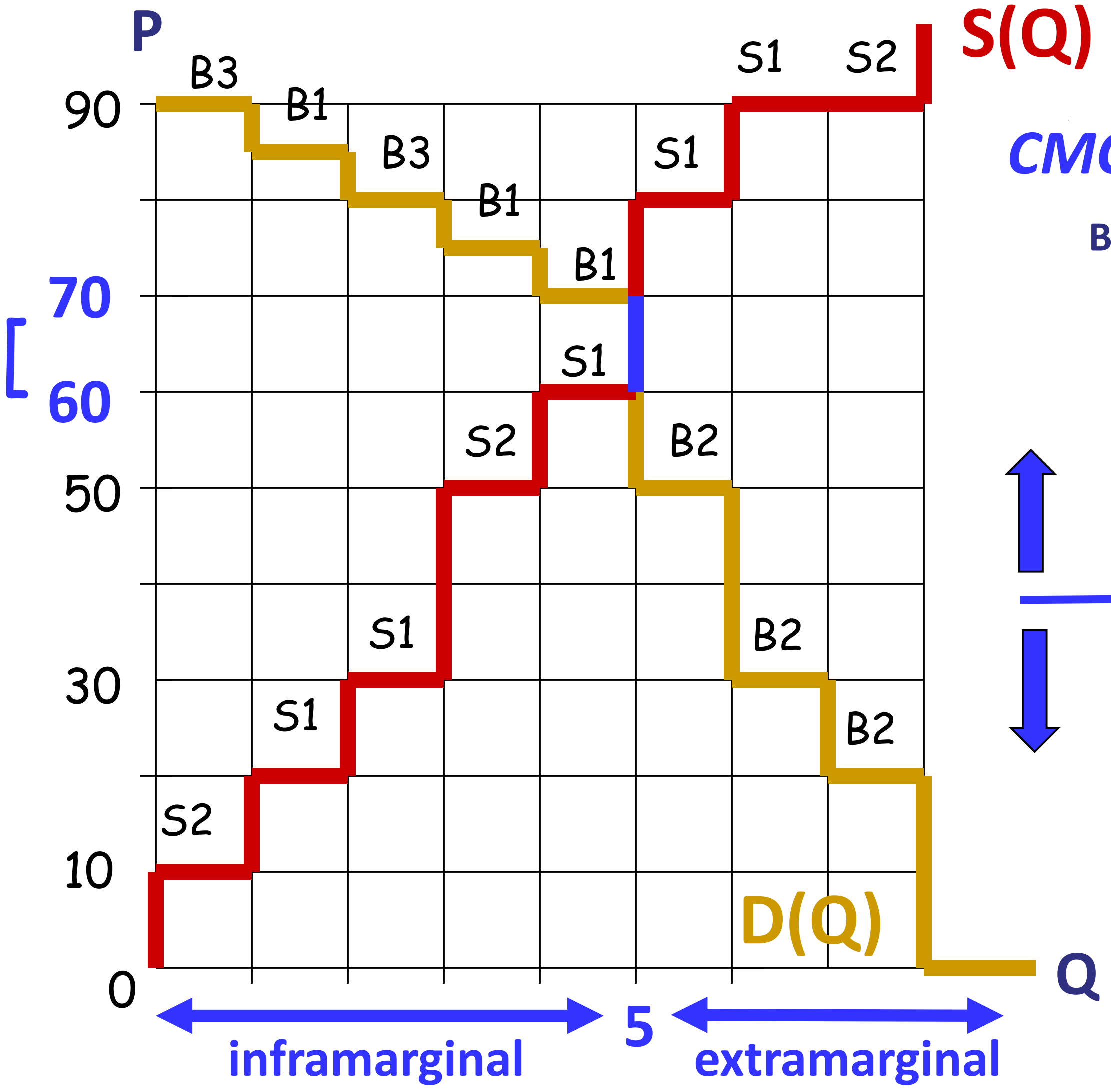
= $230 (Maximum Possible)

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 ≤ P*≤ \$70*

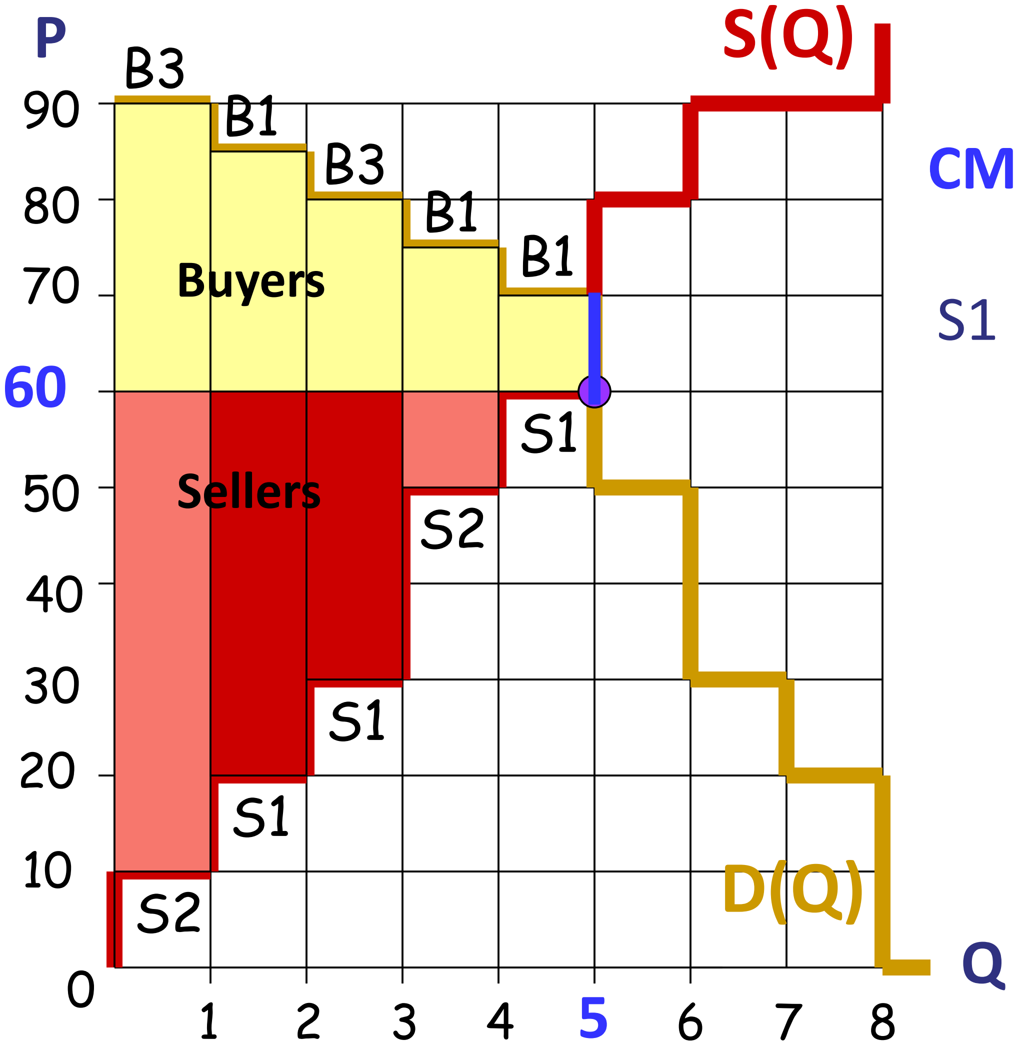
Bushels Q	MaxBuyPrice		MinSellPrice
1	\$90	>	\$10
2	\$84	>	\$20
3	\$80	>	\$30
4	\$76	>	\$50
5	\$70	>	\$60
6	\$50	<	\$80
7	\$30	<	\$90
8	\$20	<	\$90
9	\$0	<	∞

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

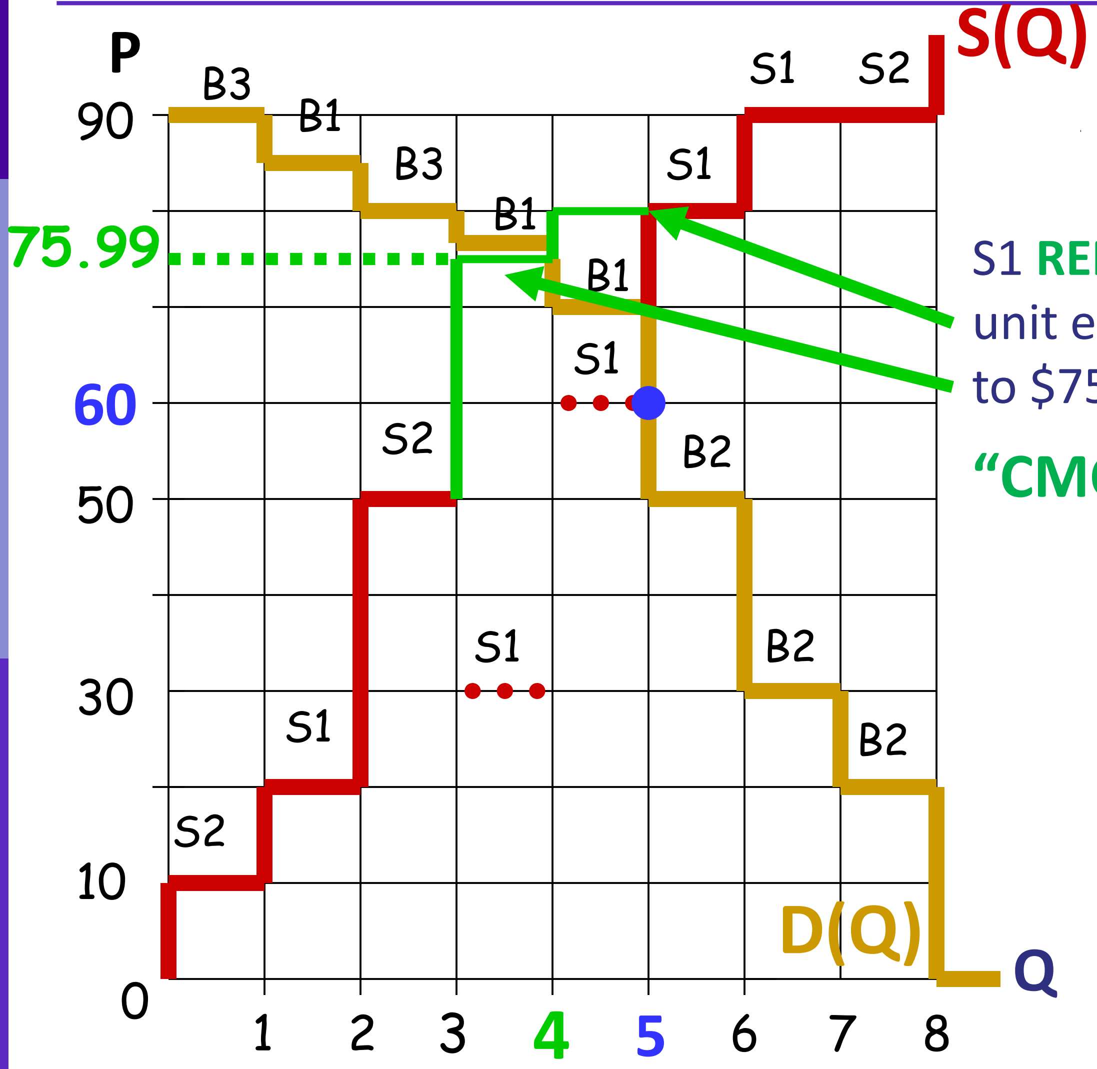
S1 Net Surplus at CMC Point:

$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 ≅ $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"**

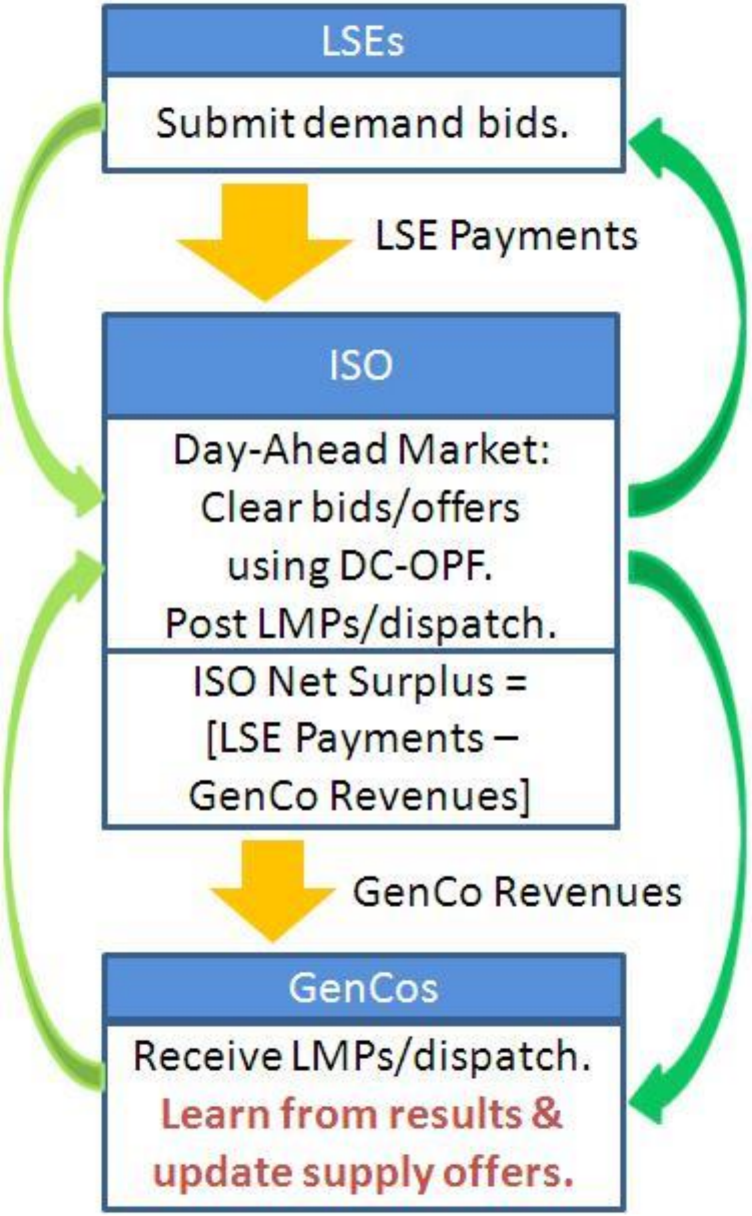
Examples: Gov't tax revenues; **<u>ISO net surplus extractions</u>** that result from grid congestion in **D**ay-**A**head **M**arkets (**DAM**s) for grid-delivered energy (MWh) settled by means of **L**ocational **M**arginal **P**rices **LMP(**b,H**)** ($/MWh) conditional on grid delivery location b 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 <u>how</u> it is extracted and <u>to what uses it is subsequently put.</u>

Discussion of double auctions, market efficiency, & social welfare specialized to an ISO managed ***D***ay-***A***head ***M***arket (***DAM***) for grid-delivered energy (MWh) with LMP settlements ($/MWh):

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



LSEs

Submit demand bids.

LSE Payments

ISO

Day-Ahead Market:
Clear bids/offers
using DC-OPF.
Post LMPs/dispatch.

ISO Net Surplus =
[LSE Payments –
GenCo Revenues]

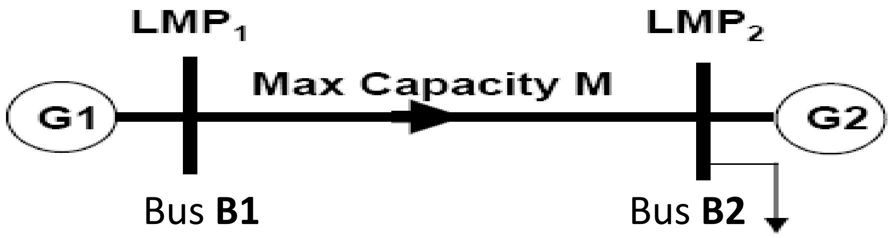
GenCo Revenues

GenCos

Receive LMPs/dispatch.
Learn from results & update supply offers.

ISO Net Surplus Extraction: DAM Example

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



$$p_L = p^F_L + p^S_L \text{ (MW)}$$

-- A **D**ay-**A**head **M**arket (**DAM**) is held on day **D** for an operating hour **H** on day **D+1**

-- The transacted good is <u>grid-delivered energy</u> (MWh), expressed in terms of power levels p (MW) to be <u>maintained</u> during hour **H** (1h)

-- **G1, G2** = Generation Companies (GenCos) located at grid buses **B1** and **B2**

-- p_L = Total demand (MW) of a **L**oad-**S**erving **E**ntity (**LSE**) at bus **B2** for hour **H**

-- p^F_L = <u>Fixed</u> (i.e., <u>not price sensitive</u>) demand (MW) of **LSE** at bus **B2** for hour **H**

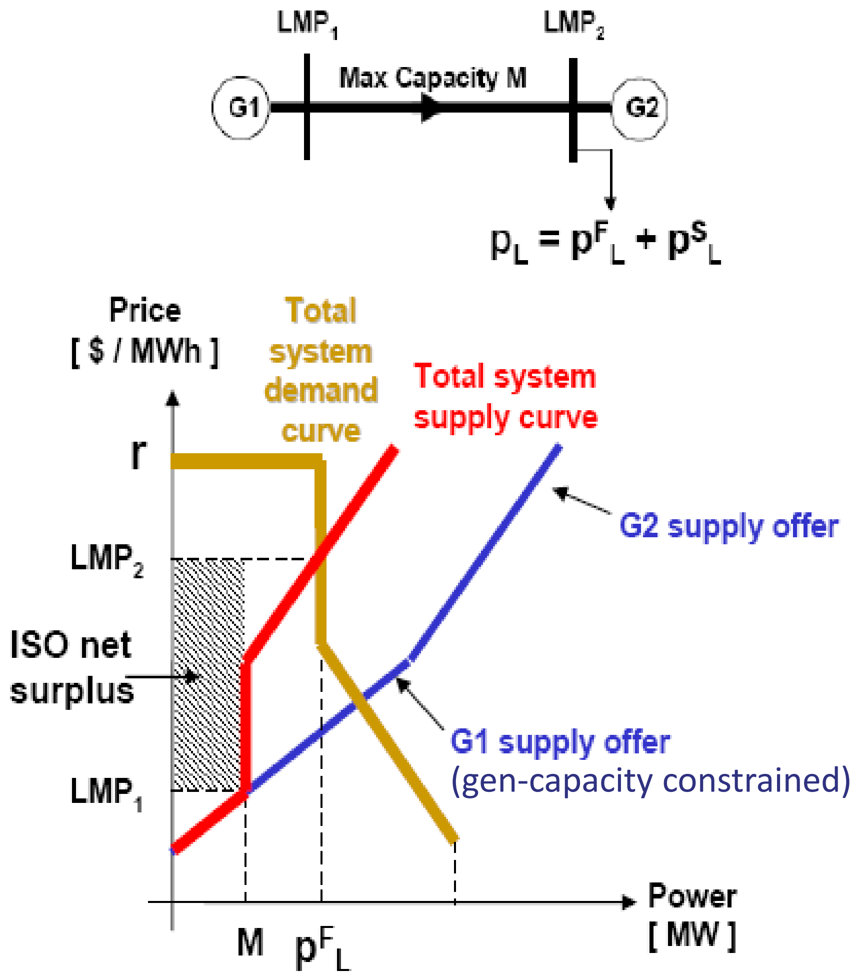
-- p^S_L = <u>Price-sensitive</u> demand (MW) of **LSE** at bus **B2** for hour **H**

-- 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** <u>retail resale</u> of fixed demand for hour **H**

ISO Net Surplus Example … Continued



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

ISO collects payment difference:

ISO Net Surplus

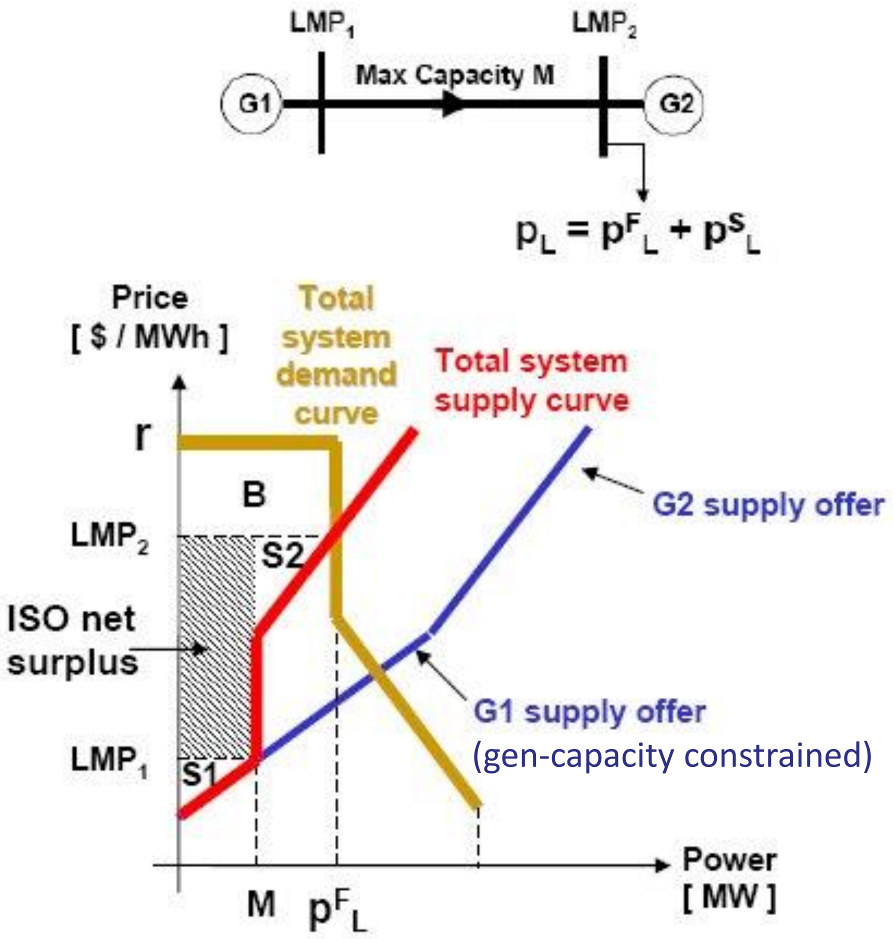
= [LSE Payments

– GenCo Revenues]

= M x $[LMP_2 – LMP_1]$

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

ISO Net Surplus Example … Continued



ISO Net Surplus:

INS = M x [LMP_2 – LMP_1]

GenCo Net Surplus:

GNS = Area S1 + Area S2

LSE Net Surplus:

LNS = Area B

Total Net Surplus:

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

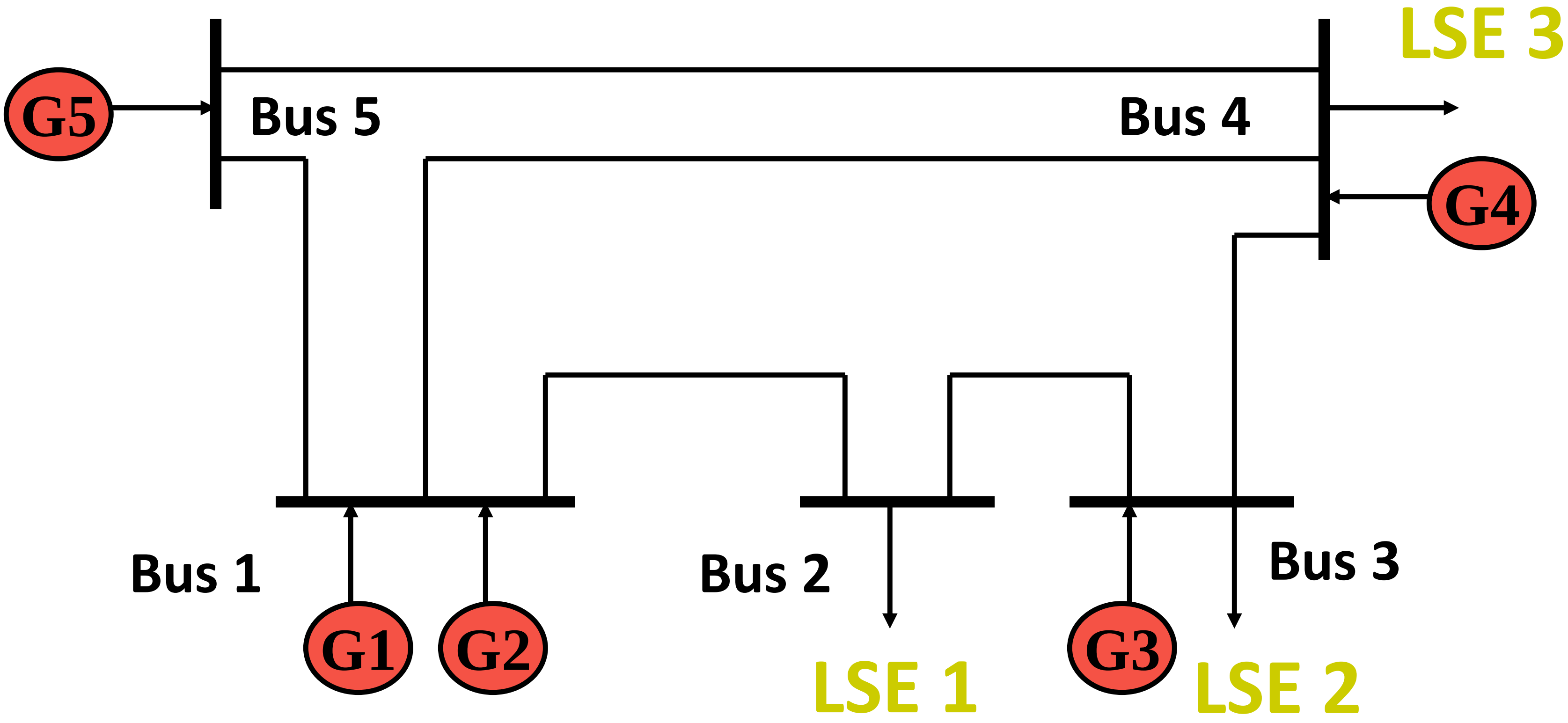
***ISO Objective** (Optimal Power Flow):*

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



AMES (V2.06) LSE Hourly Demand-Bid Formulation

- Hourly demand bid for each LSE j

Fixed + **Price-Sensitive** Demand Bids:

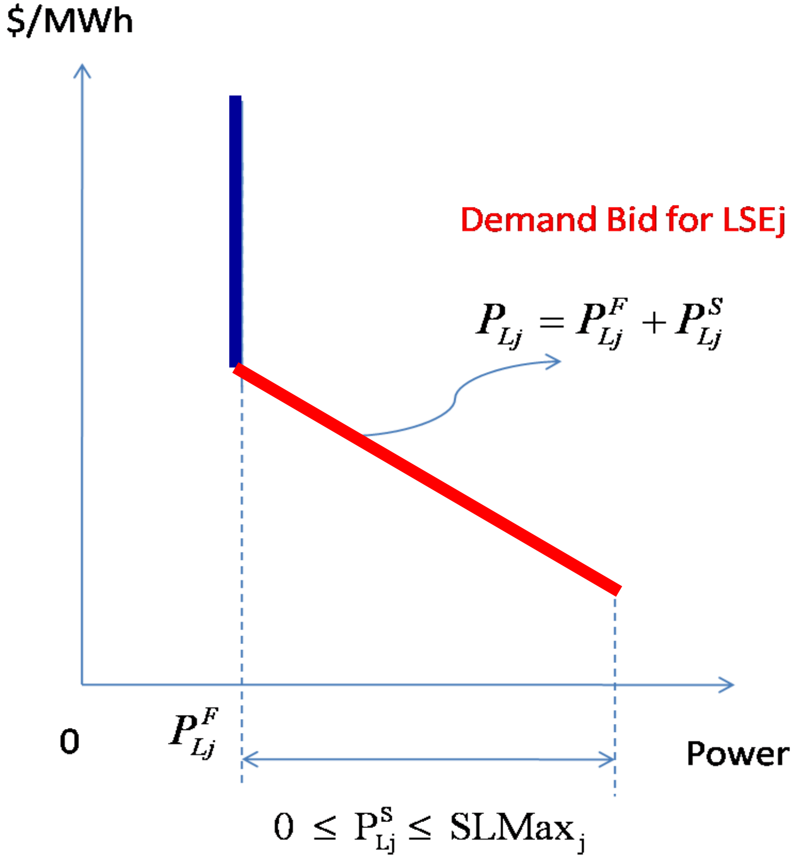
- **Fixed** demand bid =: p^F_{Lj} (MWs)
- **Price-sensitive** demand bid

  =: Inverse demand function F_j

  mapping real power p^S_{Lj} (MWs)
  over a purchase capacity interval
  into a per-unit price ($/MWh) for
  some designated hour H:

$$F_j(p^S_{Lj}) = c_j - 2d_j p^S_{Lj}$$

$$0 \le p^S_{Lj} \le SLMax_j$$



R Measure for Demand-Bid Price Sensitivity

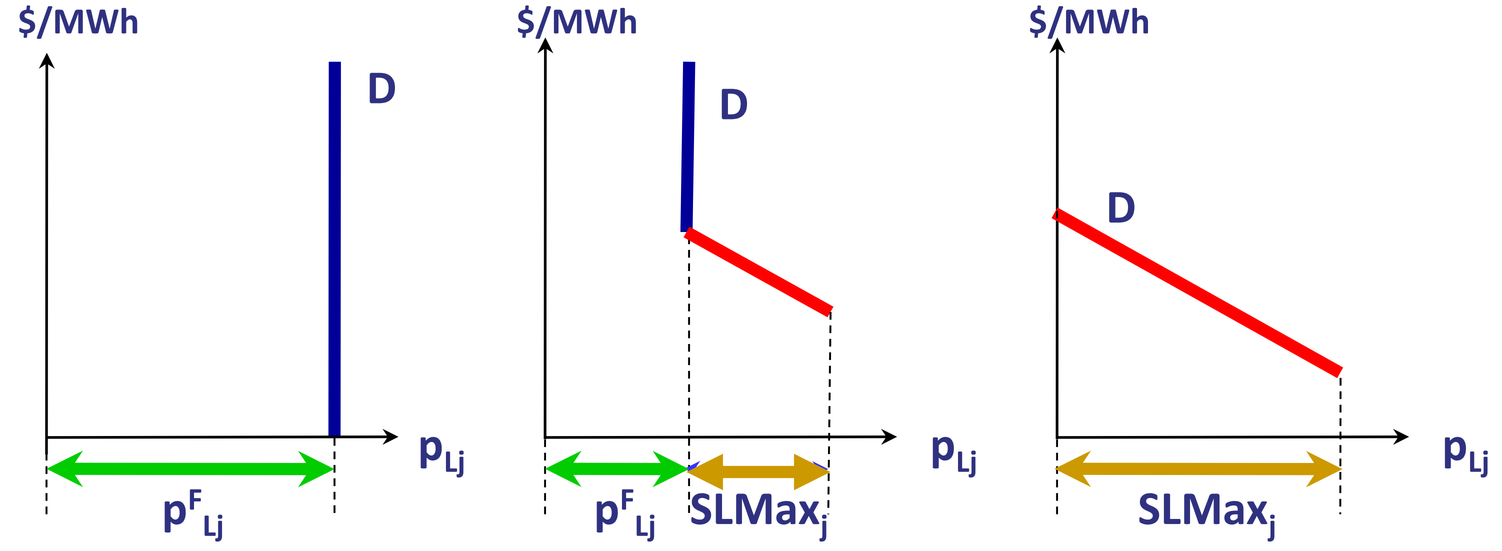
Permits price sensitivity to be systematically varied across experiments

For LSE j in Hour H:

pF_{Lj} = Fixed demand for real power (MWs)

$SLMax_j$ = Maximum potential price-sensitive demand (MWs)

$$R =: SLMax_j / [\, p^F_{Lj} + SLMax_j \,]$$



R=0.0

(100% Fixed Demand)

R=0.5

R=1.0

(100% Price-Sensitive Demand)

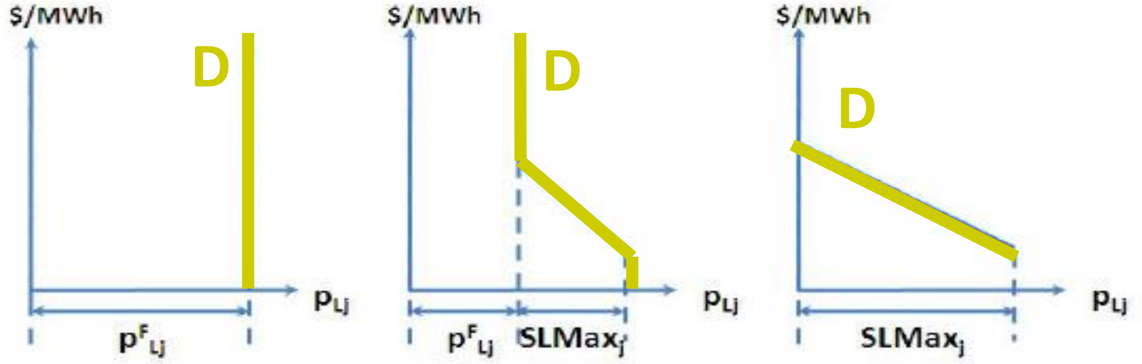
Experimental Outcomes:

Varied R (Price-Sensitivity) Measure for Demand Bids

Demand bid for LSE j (MW):

Fixed demand bid p^F_{Lj} + Price-sensitive demand bid p^S_{Lj} ,

where $0 \leq p^S_{Lj} \leq SLMax_j$



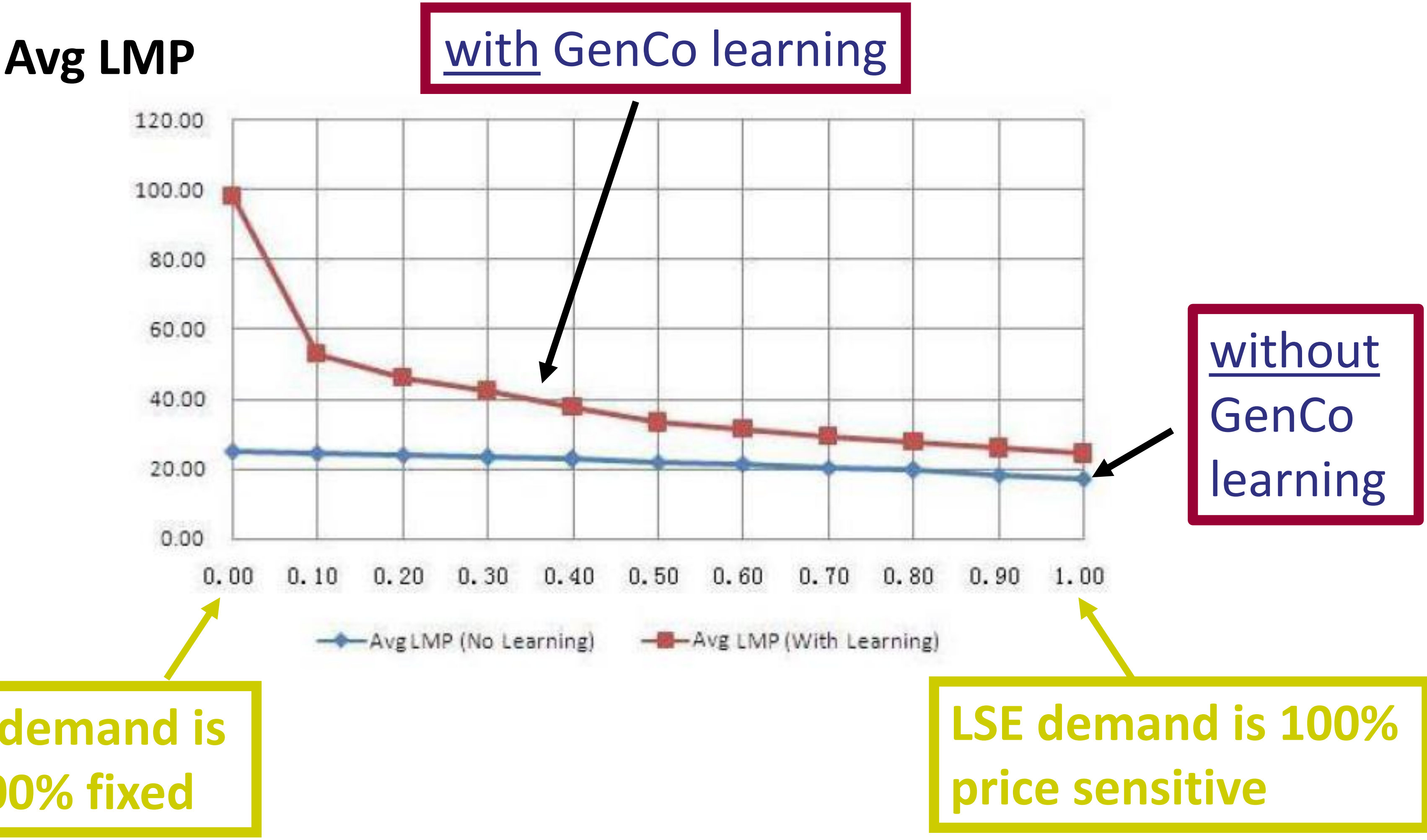
(1) R=0.0 **(2) R=0.5** **(3) R=1.0**

100% fixed demand

100% price-sensitive demand

Average LMP Outcomes on Day 1000

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



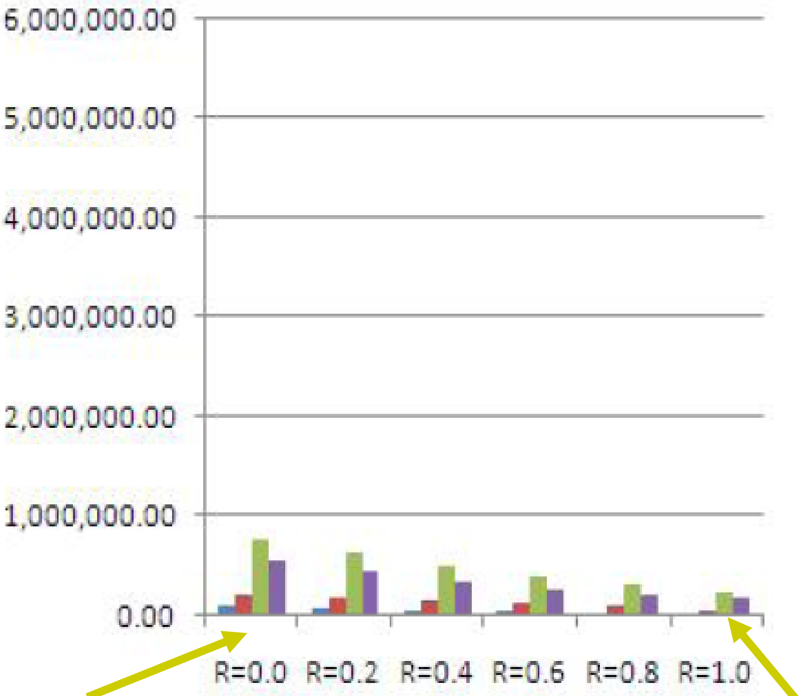
LSE demand is 100% fixed

LSE demand is 100% price sensitive

Average ISO Net Surplus Outcomes on Day 1000

for varied learning & demand treatments

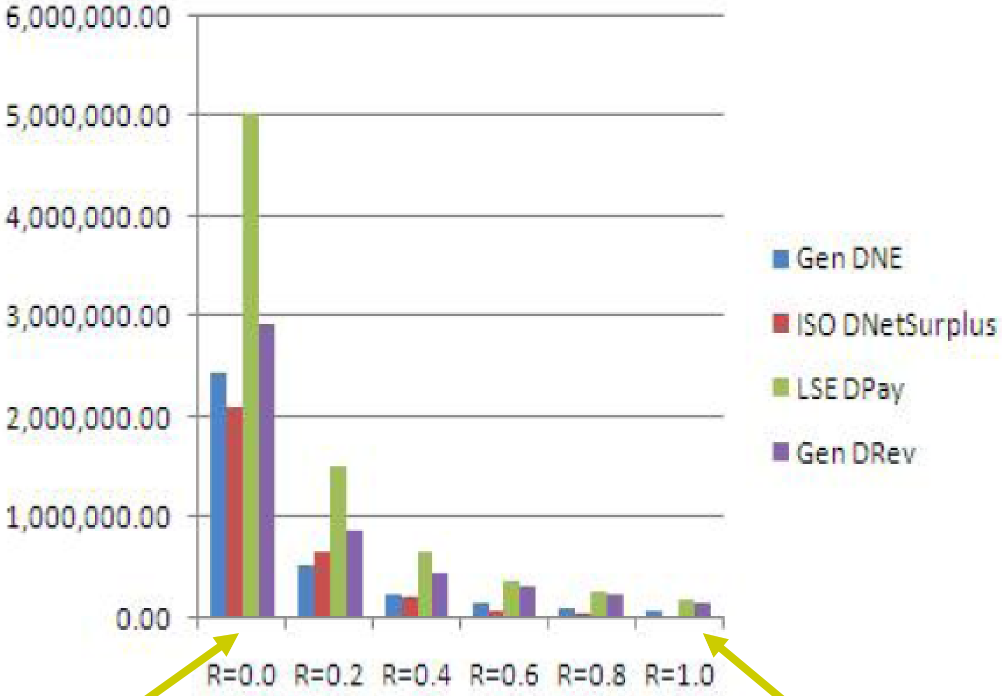
Without Learning



100% fixed

100% price sensitive

With Learning GenCos



100% fixed

100% price sensitive

🟦 = GenCo Net Earnings

🟥 = ISO Net Surplus

ISO Net Surplus Extraction: Empirical Comparisons

- **From PJM 2008 report:**
  ISO net surplus from day-ahead market: **$2.66 billion**

- **From MISO 2008 report:**
  ISO net surplus from day-ahead market: **$500 million**

- **From CAISO 2008 report:**
  ISO net surplus from day-ahead inter-zonal congestion charges: **$176 million**

- **From ISO-NE 2008 report:**
  Combined ISO net surplus for real-time and day-ahead markets: **$121 million**

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