Auction Basics for Wholesale Power Markets: Objectives and Pricing Rules

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Presentation Slides:
www.econ.iastate.edu/tesfatsi/AuctionTalk.LT.pdf

Presentation Outline

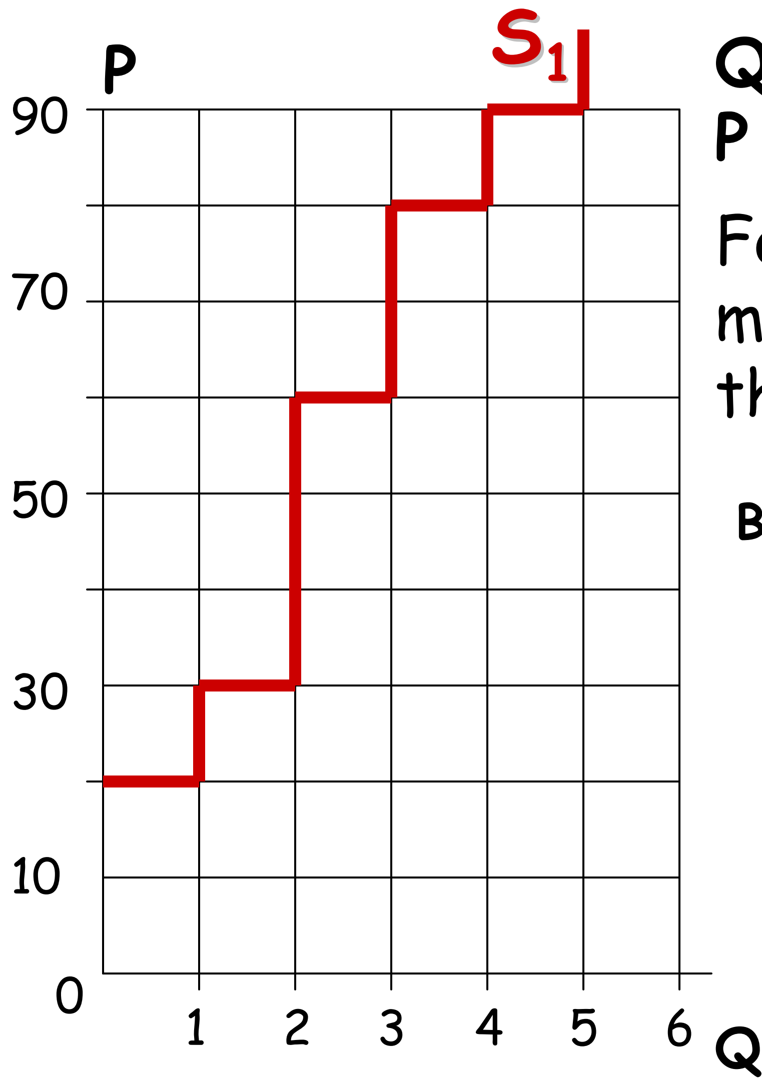
- Introduction
- Double auction basics for power markets
  - Supply, demand, & market equilibrium
  - Net surplus extraction
- Market efficiency vs. social welfare: Implications for ISOs in power markets
- Illustrative experimental results for a 5-bus test case with learning generators

Introduction

- In many regions of U.S., wholesale electric power is sold in part through "day-ahead" energy markets designed as double auctions.
- ***Double Auction (DA)*** = Centrally cleared market in which sellers submit supply offers and buyers submit demand bids.
- After review of basic DA concepts, efficiency & welfare issues arising from use of DAs for day-ahead energy markets will be discussed.

DOUBLE-AUCTION BASICS: EXAMPLE

Seller 1 Supply Offer: $P = S_1(Q)$



Q = Apple quantity (in bushels)
P = Price of apples ($ per bushel)

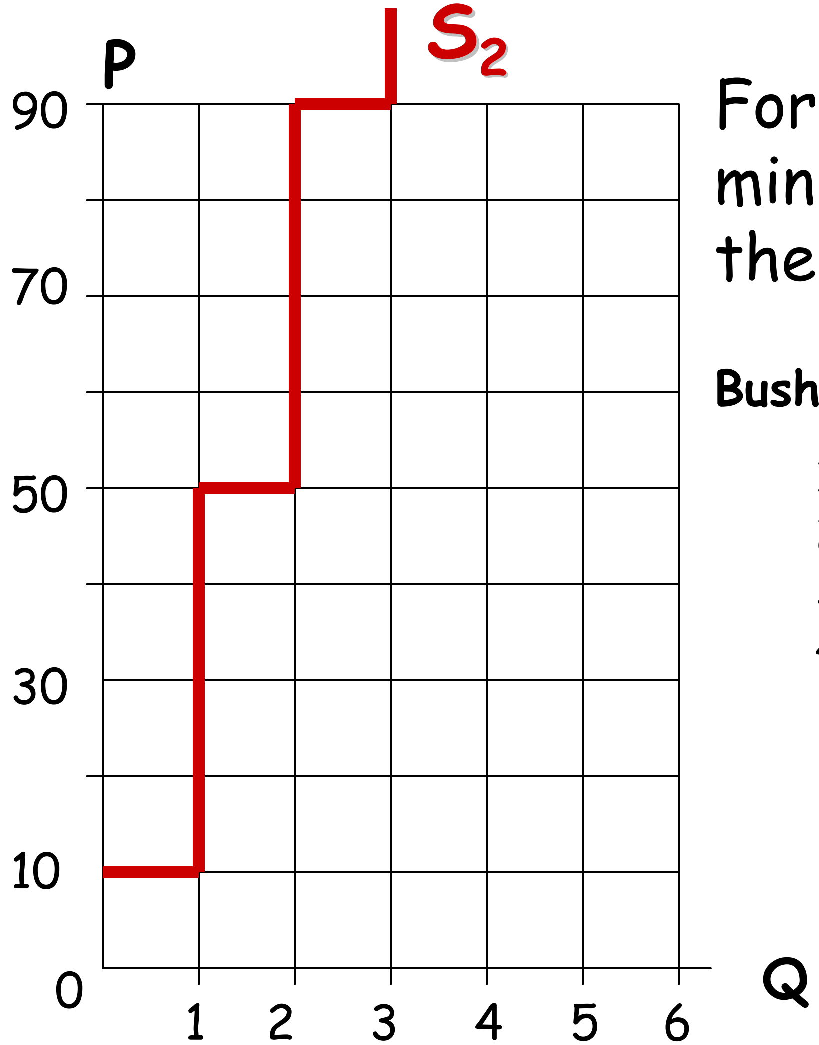
For each Q: $P=S_1(Q)$ is Seller 1's minimum acceptable sale price for the last bushel it supplies at Q.

Bushels Q	Seller 1 Min Sale Price P
1	$20
2	$30
3	$60
4	$80
5	$90
6	∞

5 = Capacity Limit

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

Seller 2 Supply Offer: $P = S_2(Q)$

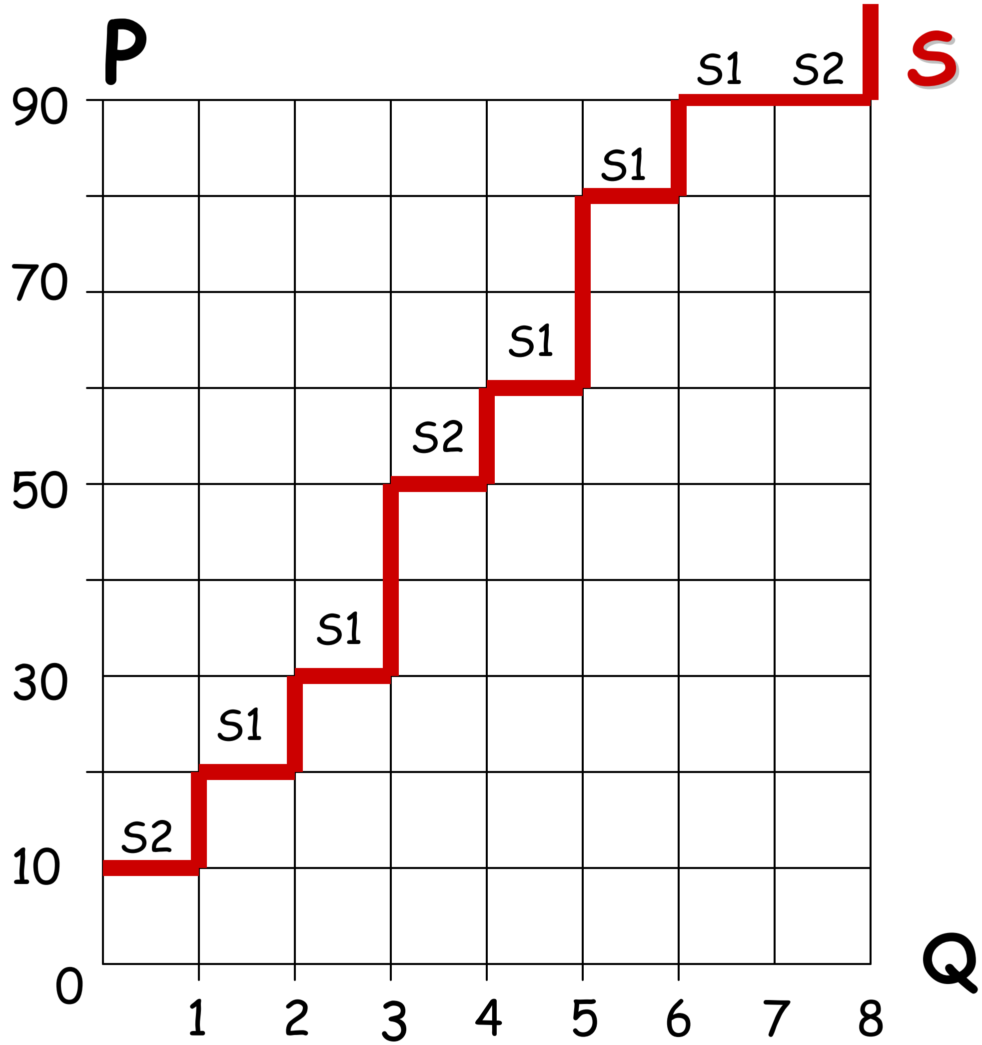


For each Q: $P=S_2(Q)$ is Seller 2's minimum acceptable sale price for the last bushel it supplies at Q.

Bushels Q	Seller 2 Min Sale Price P
1	\$10
2	\$50
3	\$90
4	∞

3 = Capacity Limit

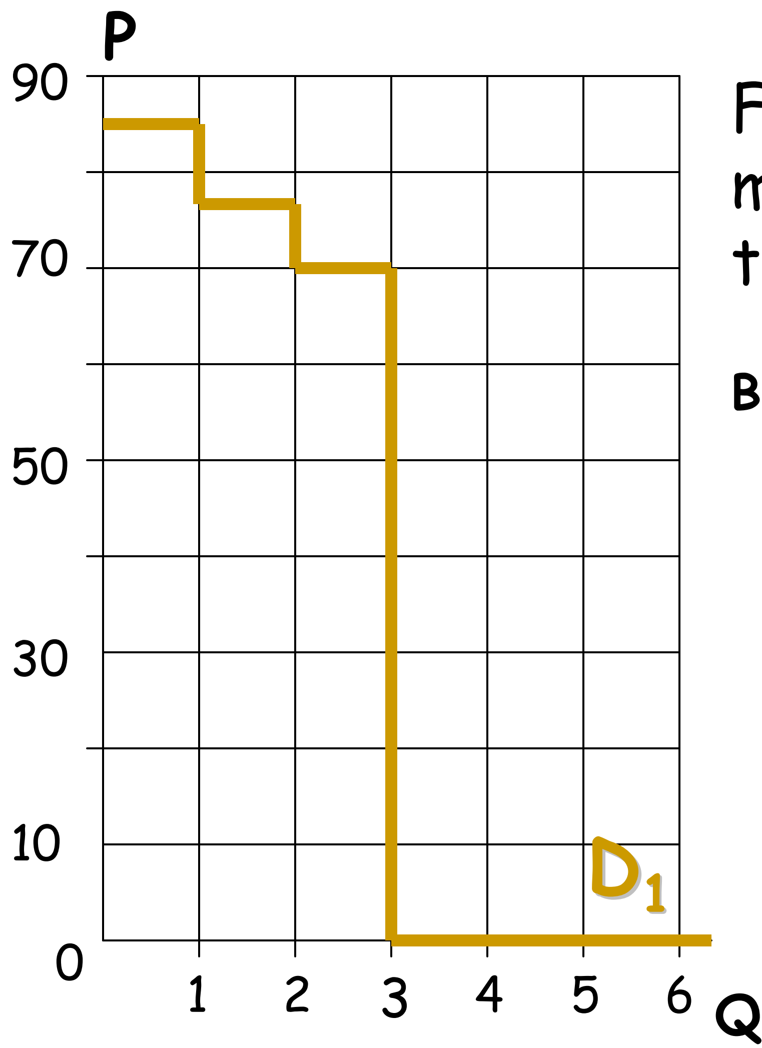
Total System (Inverse) Supply Function: P=S(Q)



Bushels Q	Minimum Seller Sale Price P
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	∞

Total supply capacity = 8 bushels of apples

Buyer 1 Demand Bid: $P = D_1(Q)$

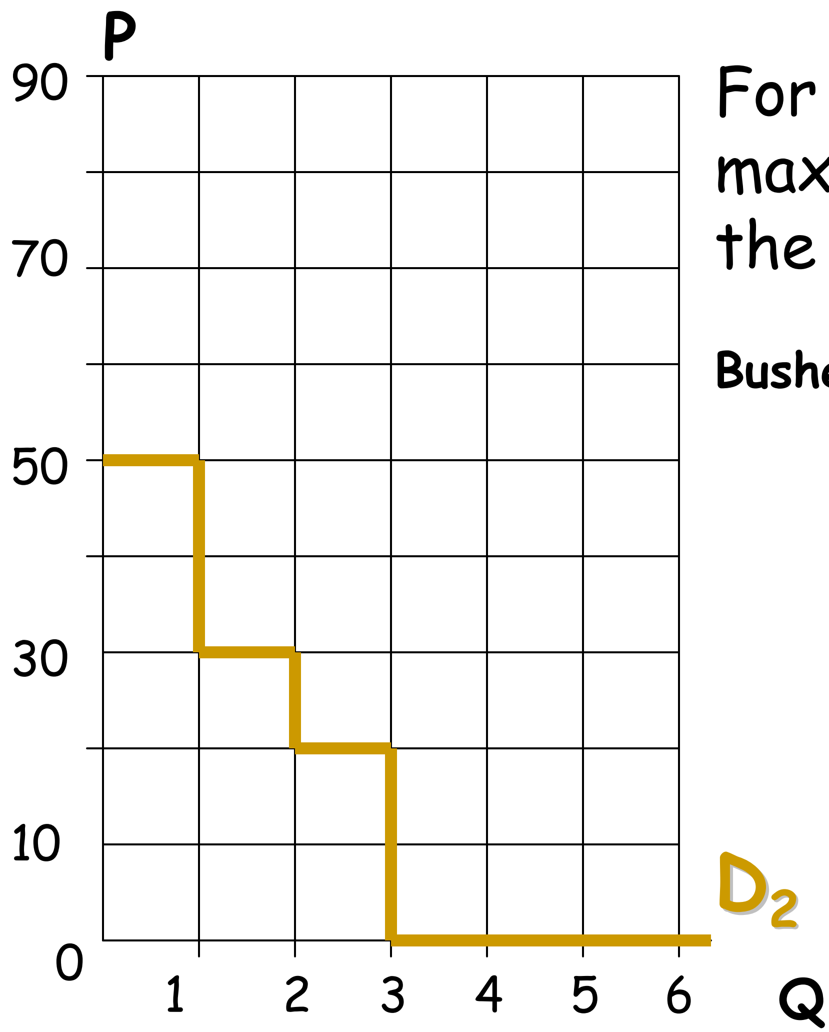


For each Q: $P=D_1(Q)$ is Buyer 1's max purchase price ($/bushel) for the last bushel it purchases at Q.

Bushels Q	Buyer 1 Max Purchase Price P
1	$84
2	$76
3	$70
4	$ 0

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

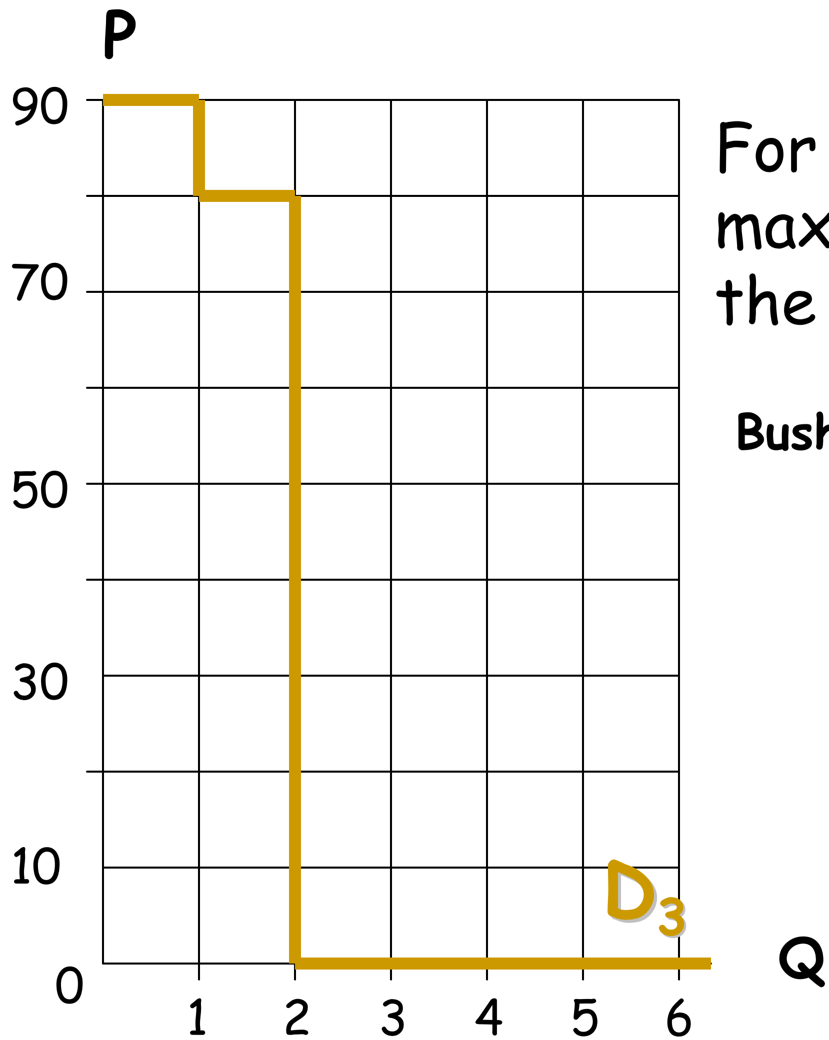
Buyer 2 Demand Bid: $P = D_2(Q)$



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	Buyer 2 Max Purchase Price P
1	$50
2	$30
3	$20
4	$ 0

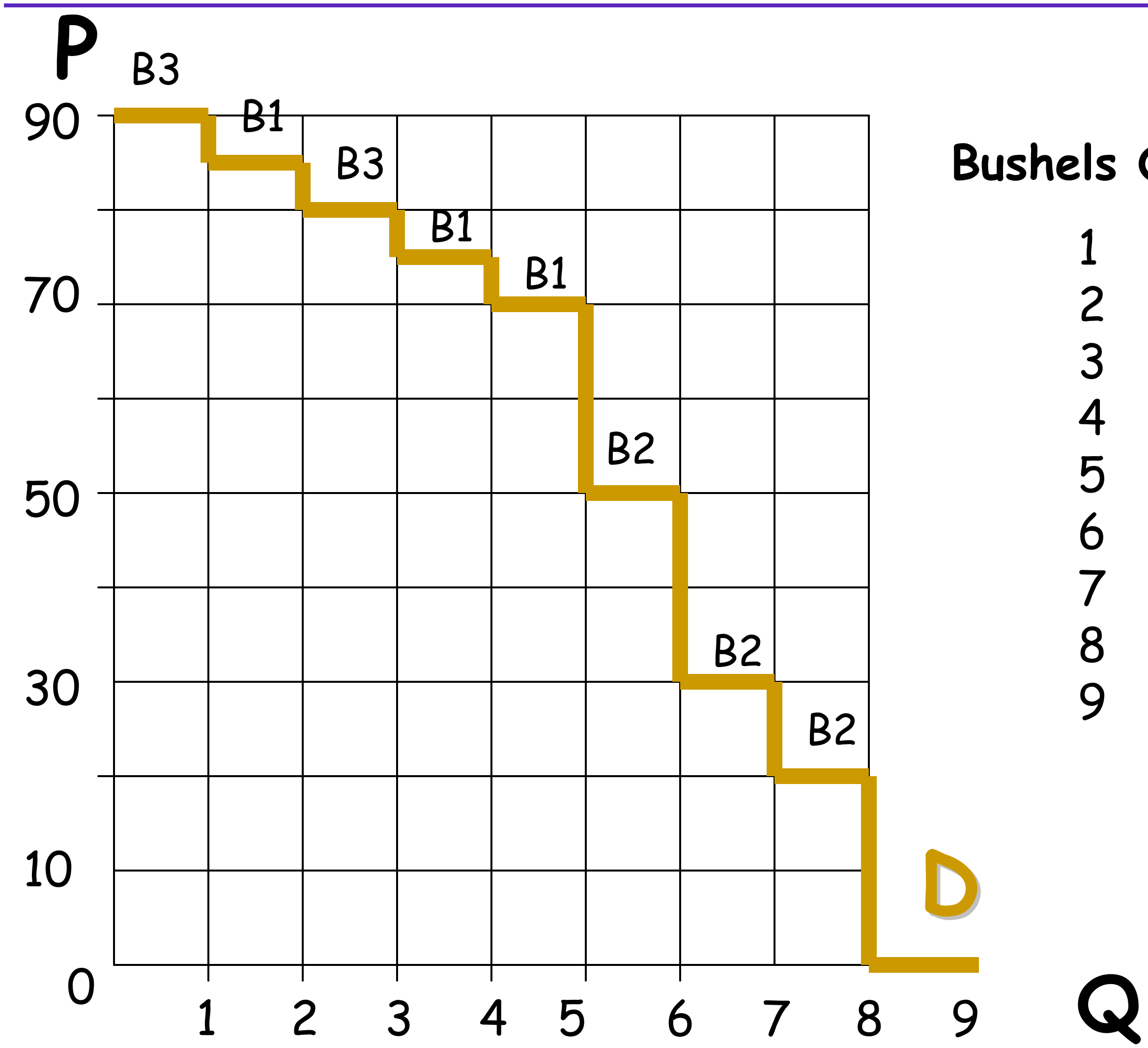
Buyer 3 Demand Bid: $P = D_3(Q)$



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	Buyer 3 Max Purchase Price P
1	$90
2	$80
3	$ 0

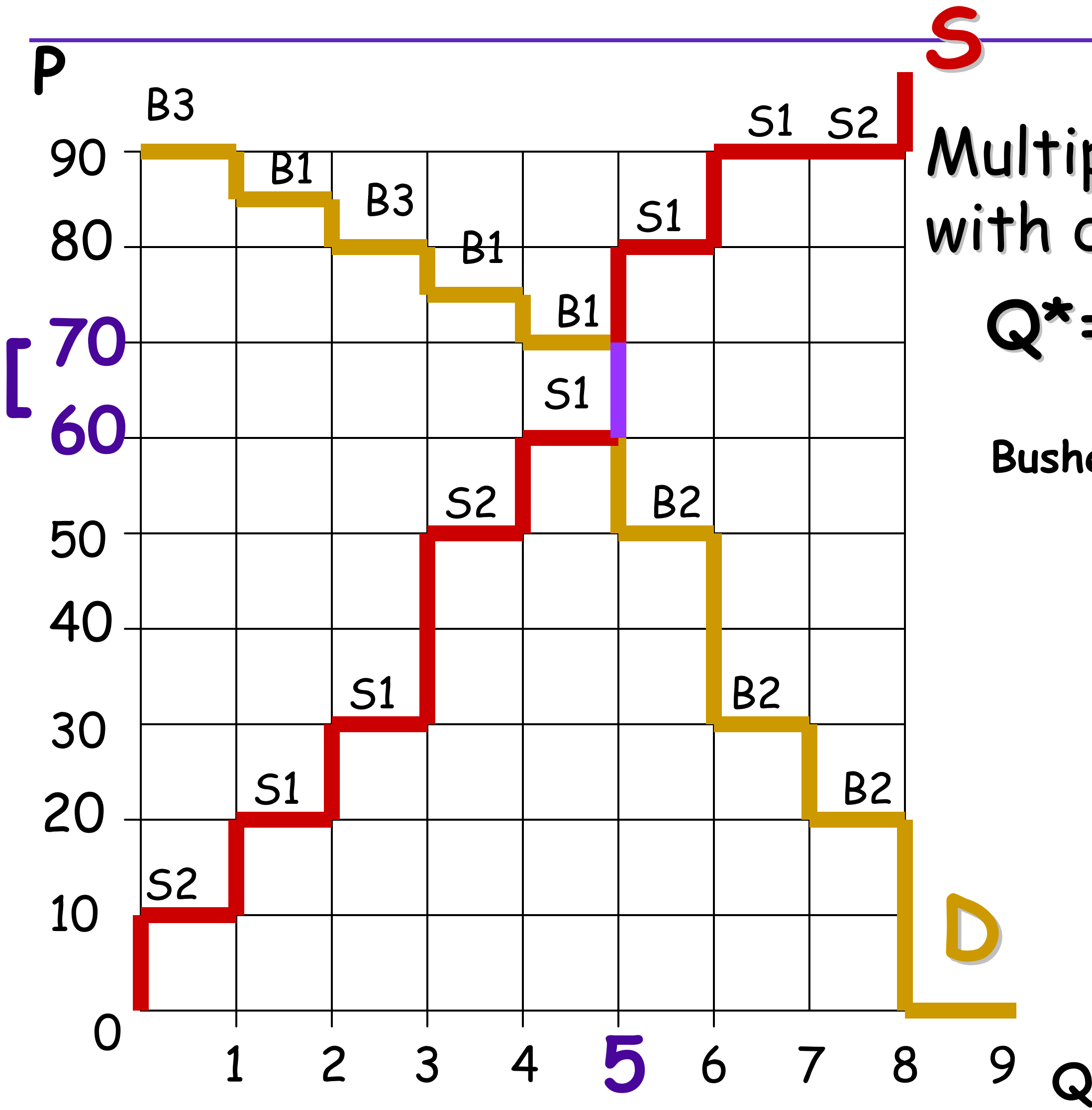
Total System (Inverse) Demand Function: P=D(Q)



Bushels Q	Maximum Buyer Purchase Price P
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 Points: S=D

Uniform Pricing Rule: One Market Price P* ($/bushel) per CMC Point

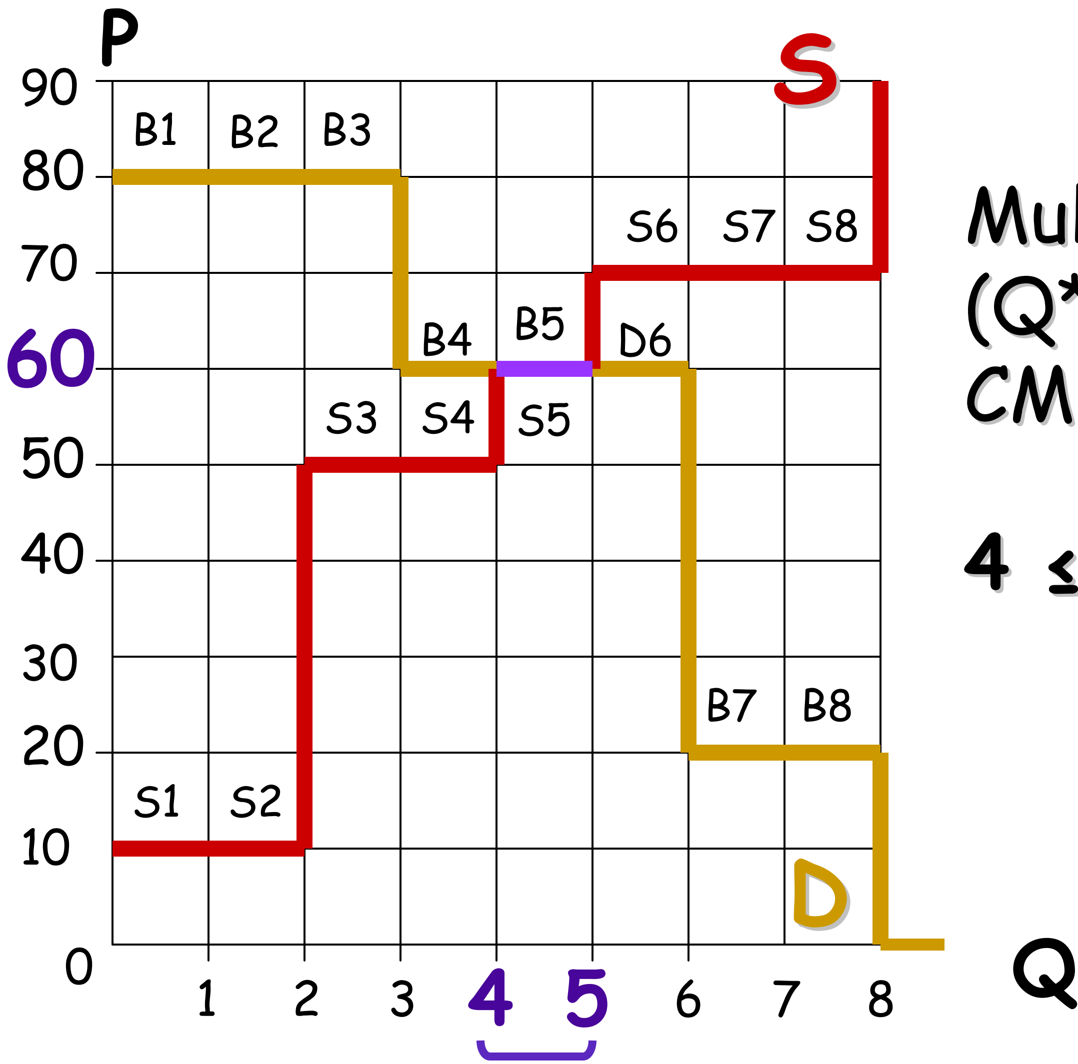


Multiple CMC points (Q*,P*), with different CMC prices P*:

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	∞

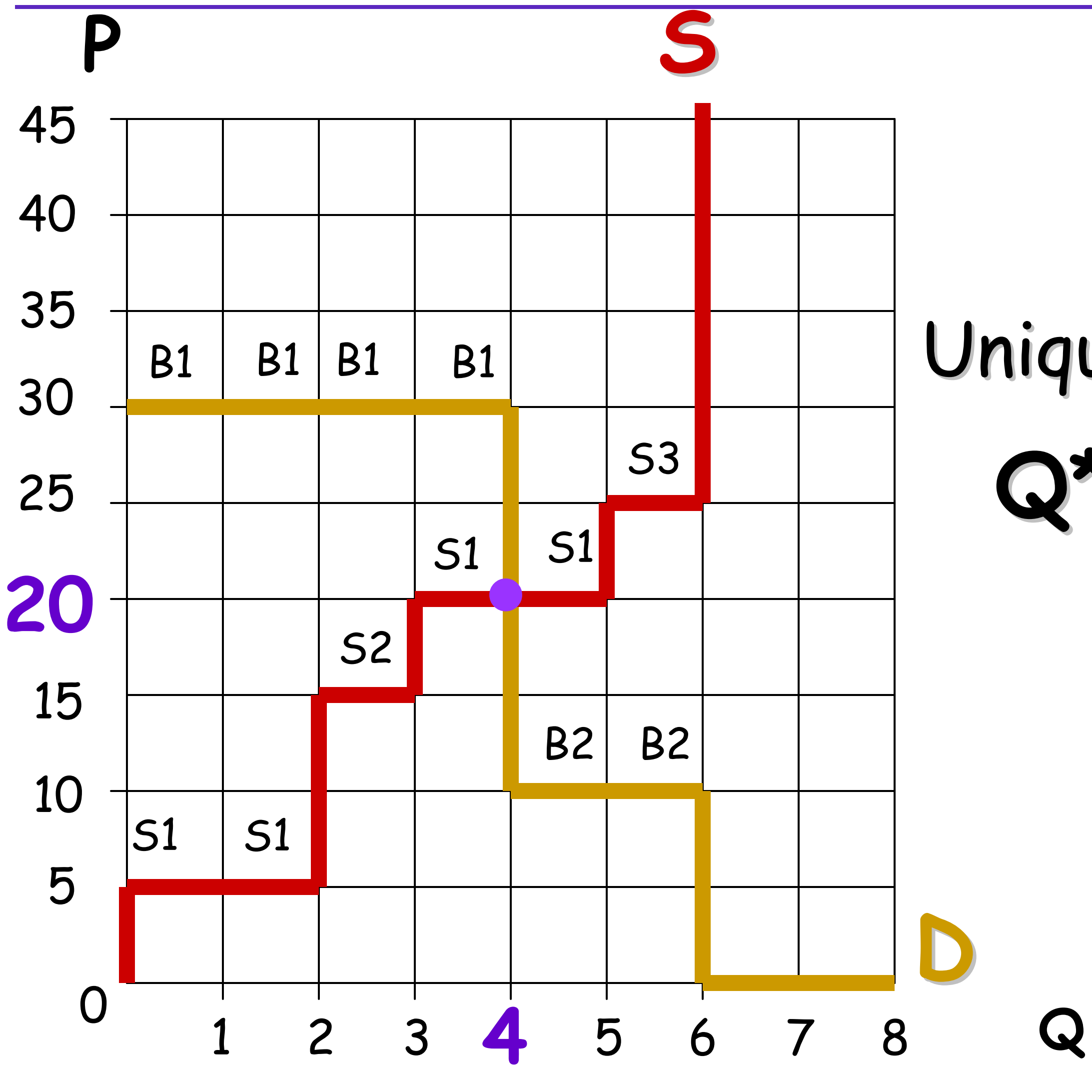
Can also have multiple CMC points with a range of CMC quantities



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

4 ≤ Q*≤ 5, P*=$60

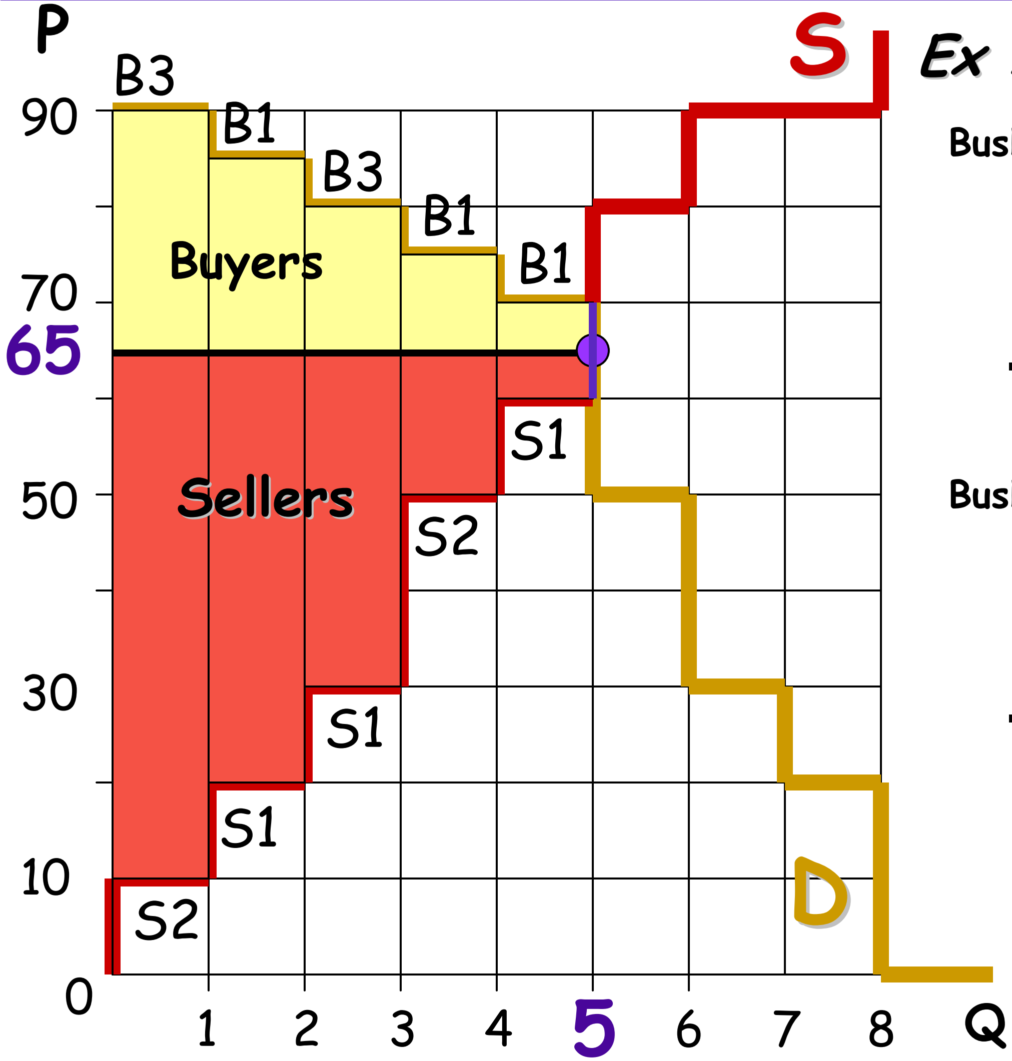
Can also have a unique CMC point



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

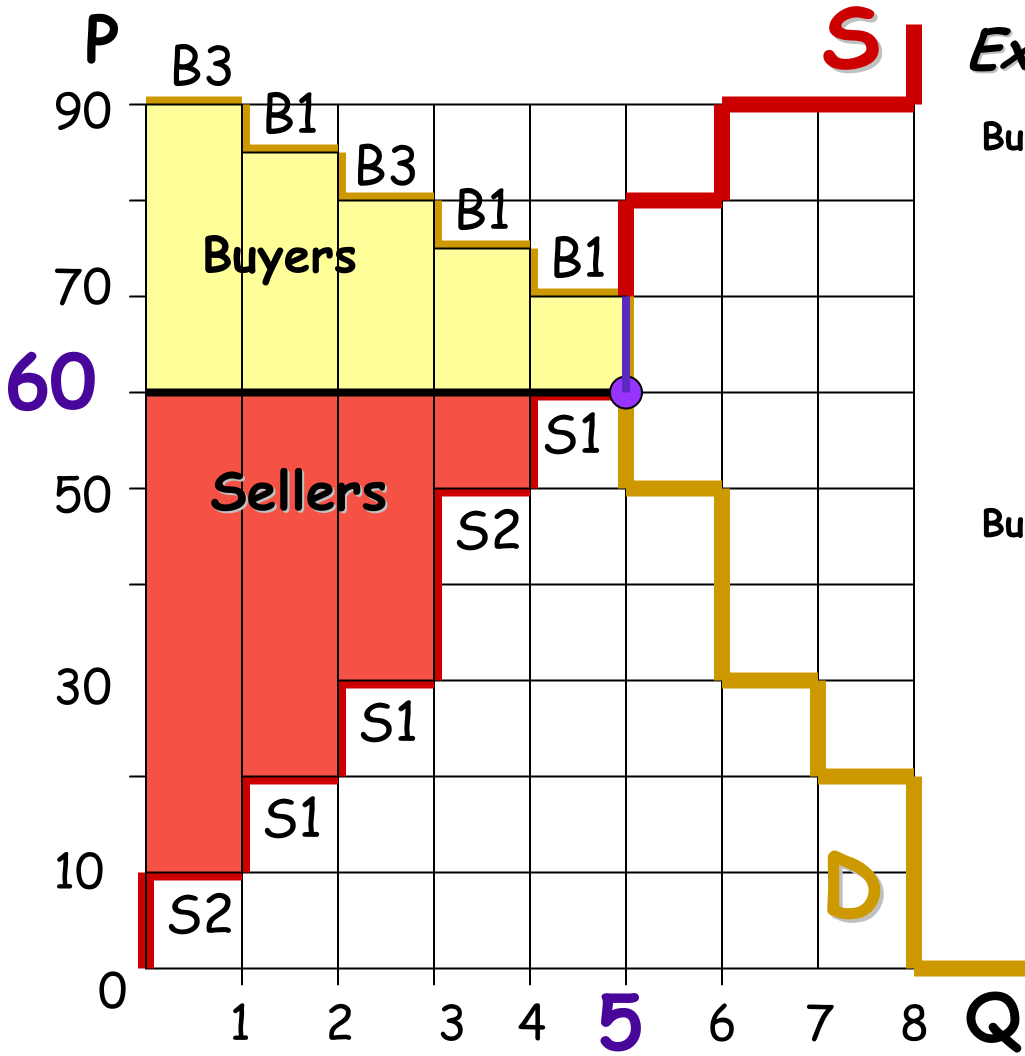
BUYER NET SURPLUS: $75

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	MaxBPrice		P*=60		BuyNetSur
1	$90	-	$60	=	$30
2	$84	-	$60	=	$24
3	$80	-	$60	=	$20
4	$76	-	$60	=	$16
5	$70	-	$60	=	$10

BUYER NET SURPLUS: $100

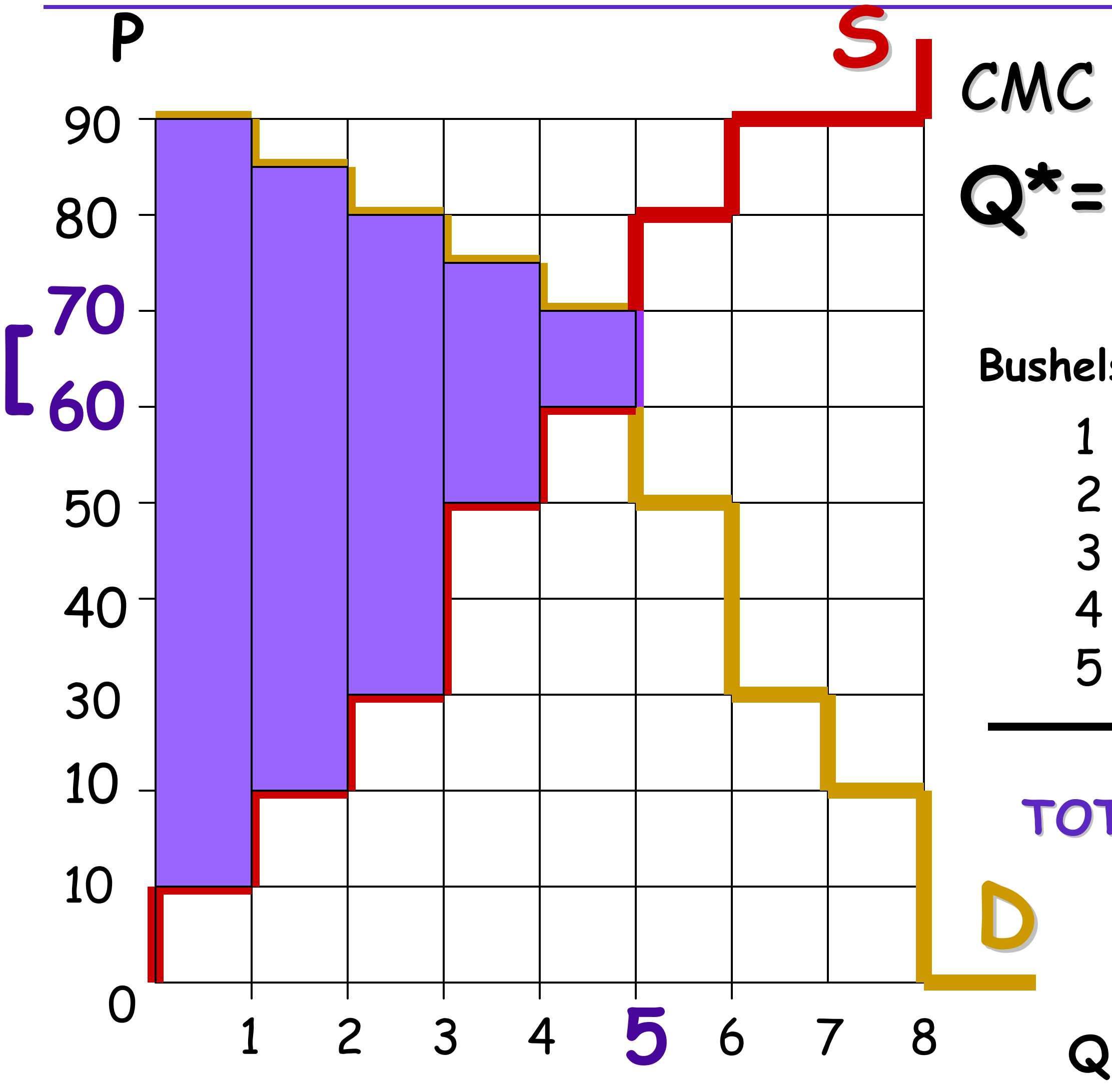
Bushels Q	P*=65		MinSPrice		SellNetSur
1	$60	-	$10	=	$50
2	$60	-	$20	=	$40
3	$60	-	$30	=	$30
4	$60	-	$50	=	$10
5	$60	-	$60	=	$ 0

SELLER NET SURPLUS: $130

Total Net Surplus: $230

Total Net Surplus at a CMC Point

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



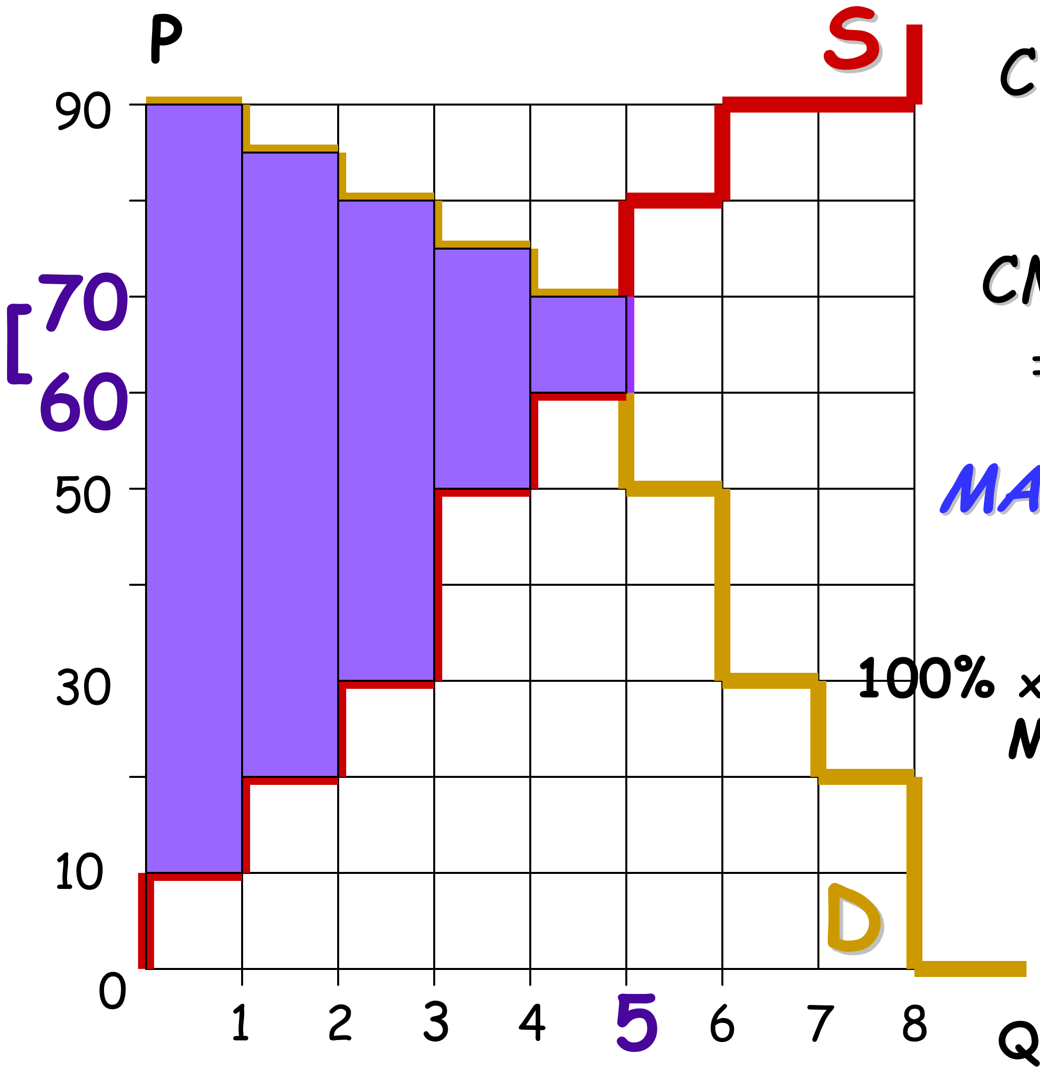
CMC Points:

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

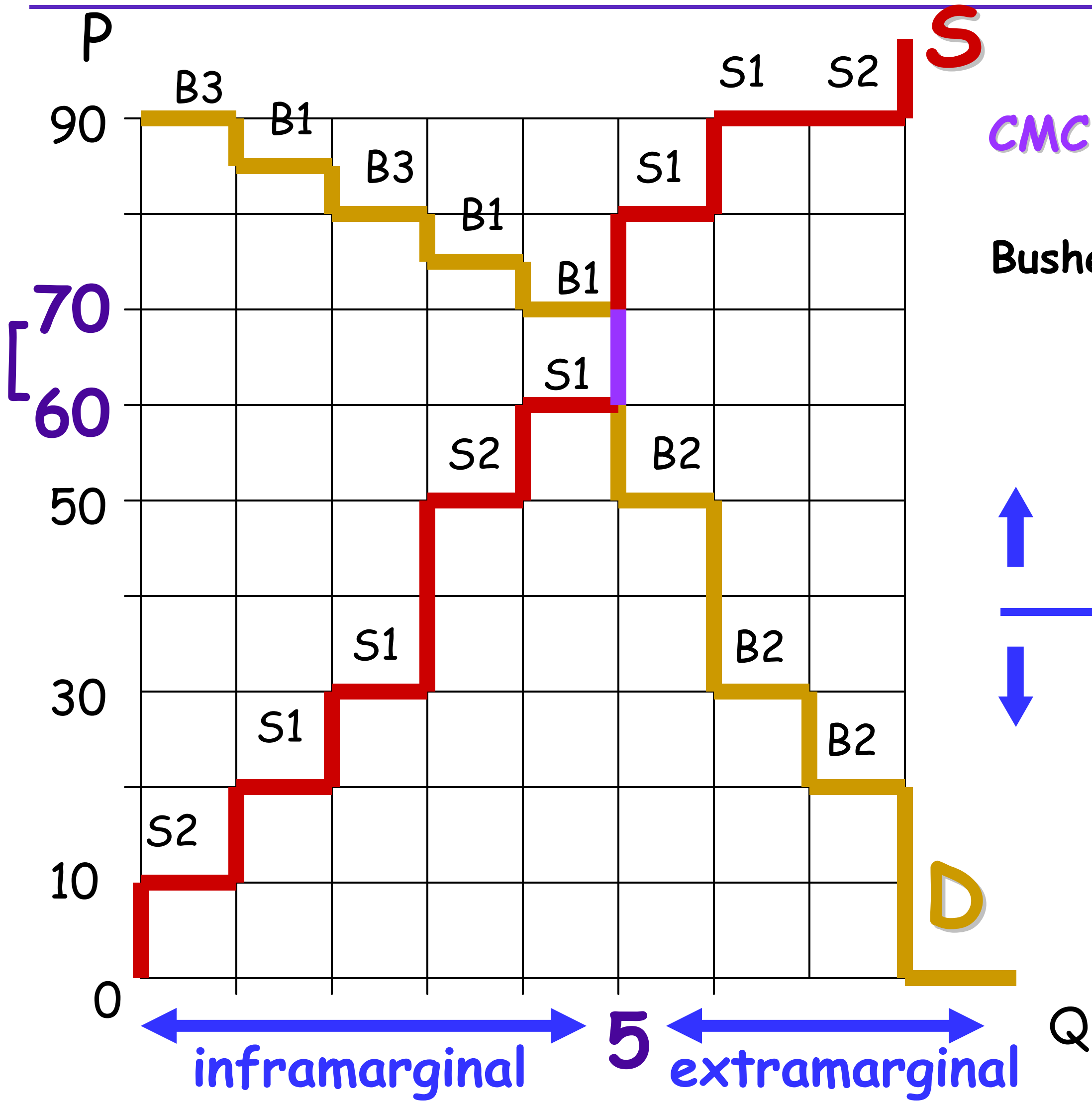
= $230 (Maximum Possible)

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

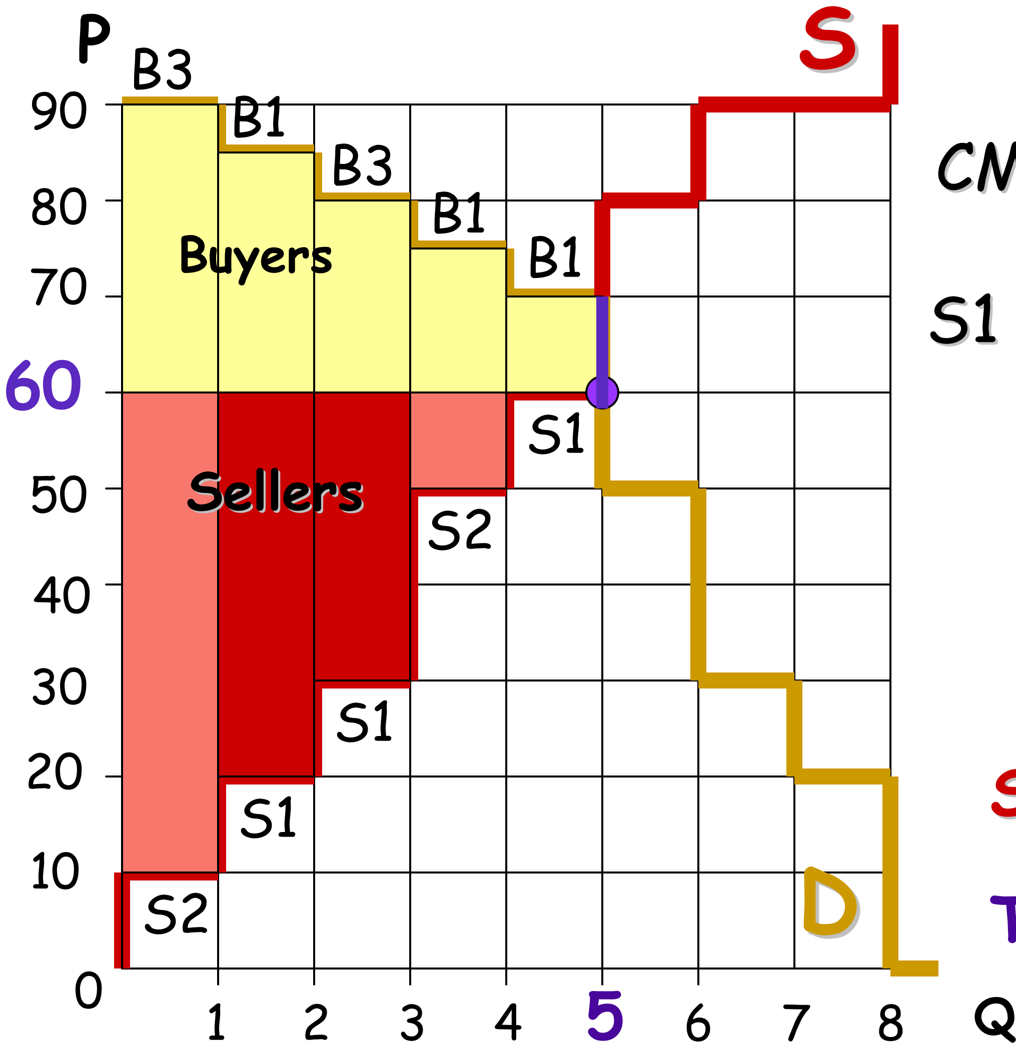
Bushels Q	MaxBuyPrice		MinSellPrice
1	$90	>	$10
2	$84	>	$20
3	$80	>	$30
4	$76	>	$50
5	$70	>	$60
6	$50	<	$80
7	$30	<	$90
8	$20	<	$90
9	0		∞

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/buyer to extract more net surplus than he achieves at a CMC point

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



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

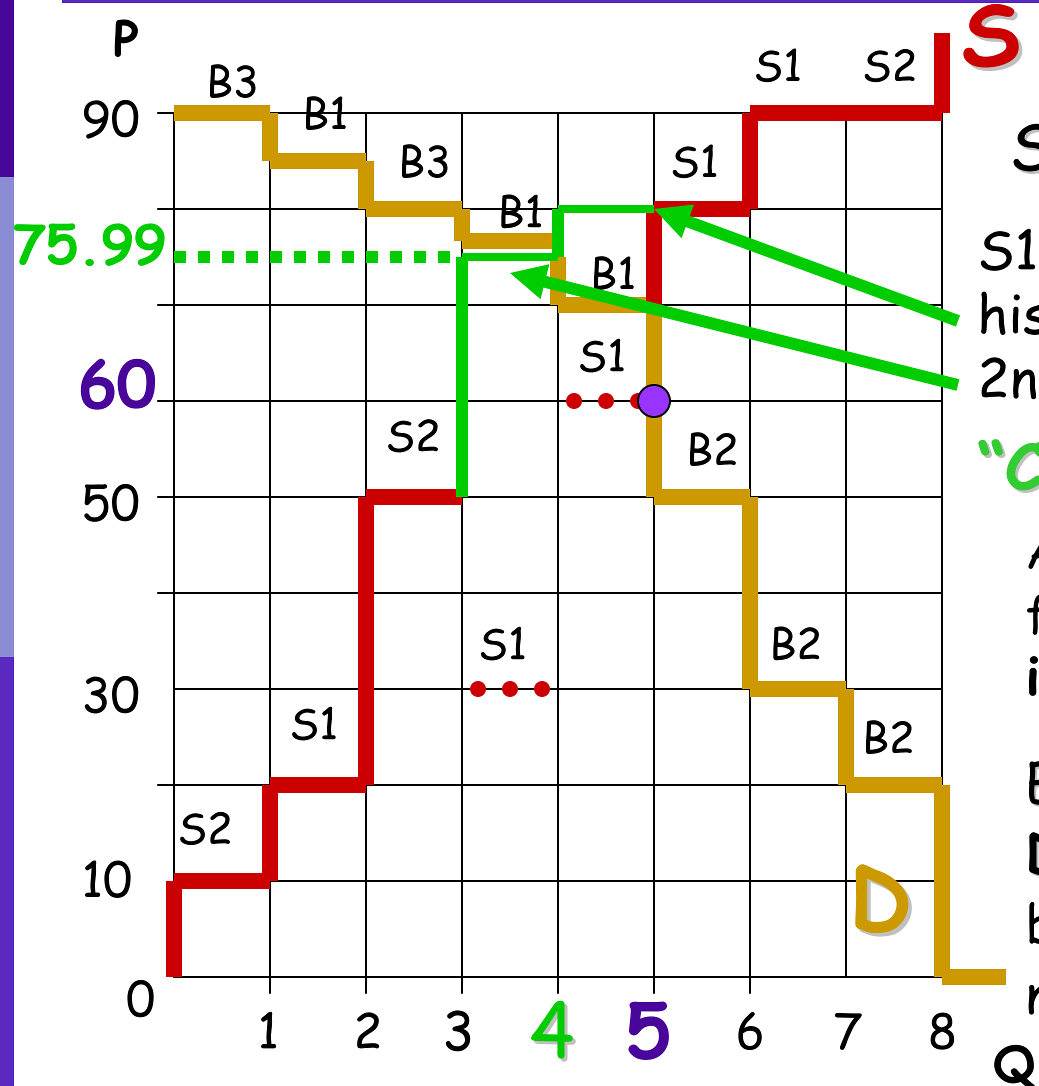
S1 Net Surplus at CMC Point:

$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" Pt: Q'=4, P'≅$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 very narrow measure of resource non-wastage.
- Ideally, should measure ***social*** efficiency (resource non-wastage across all markets and across all current and future time periods).
- Economists measure ***social welfare*** in terms of the "utility" (well-being) of ***people*** in their roles as ***consumers*** 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 seller < price P_B charged to buyer for some quantity unit sold in a market

  → Net surplus [P_B-P_S] is extracted by a "third party"

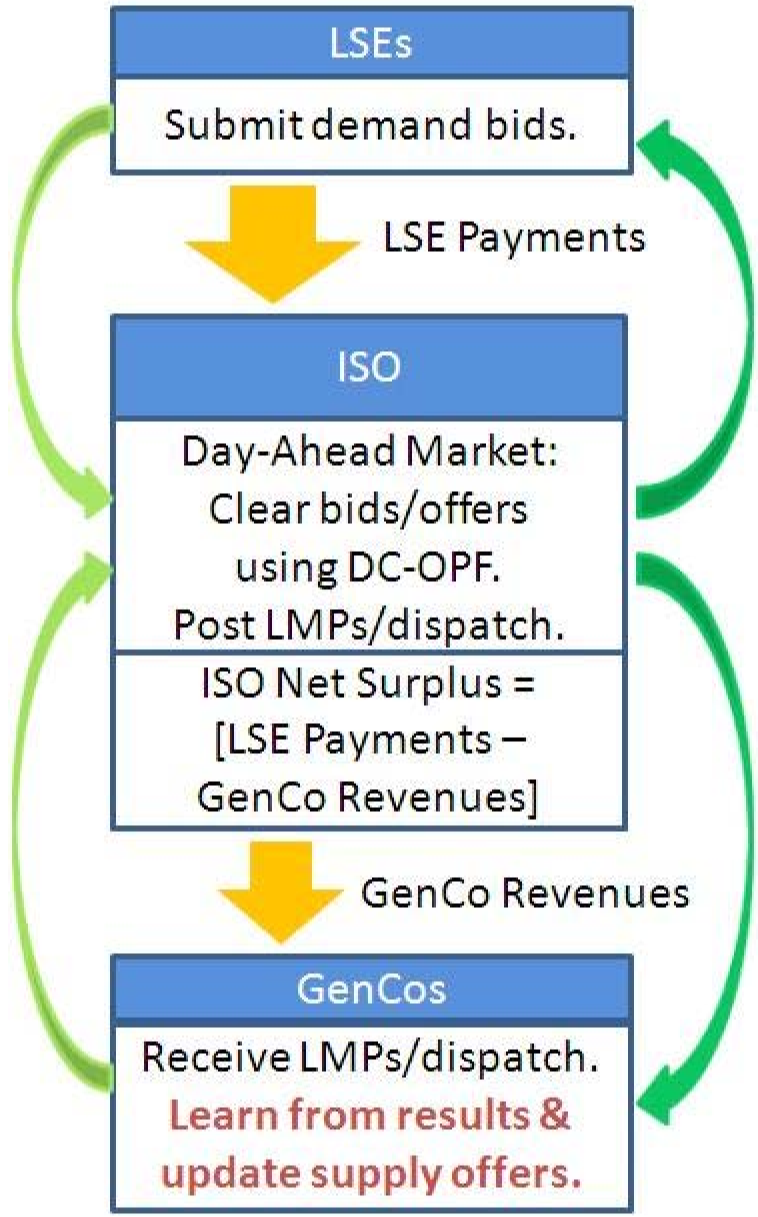
  Examples: Gov't tax revenues, **ISO net surplus extractions resulting from grid congestion in power markets with** ***locational marginal pricing (LMP)***

- "First order effect" of this third-party extraction is a decrease in the net surplus going to sellers & buyers.

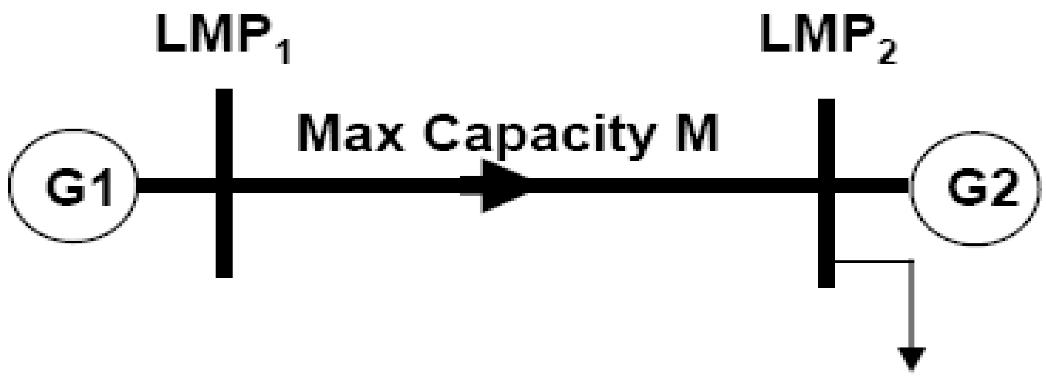
- Social efficiency/welfare implications depend on means of determination and subsequent use made of this third-party extracted net surplus.

Discussion of double auctions, market efficiency and social welfare, specialized to ISO-managed day-ahead energy markets with LMP:

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



ISO Net Surplus Extraction: Example
(adapted from H. Salazar, MS Thesis, Nov 2008)



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

G1, G2 = **Generation Companies (GenCos)**

p_L = Total demand of **Load-Serving Entity (LSE)** at bus 2

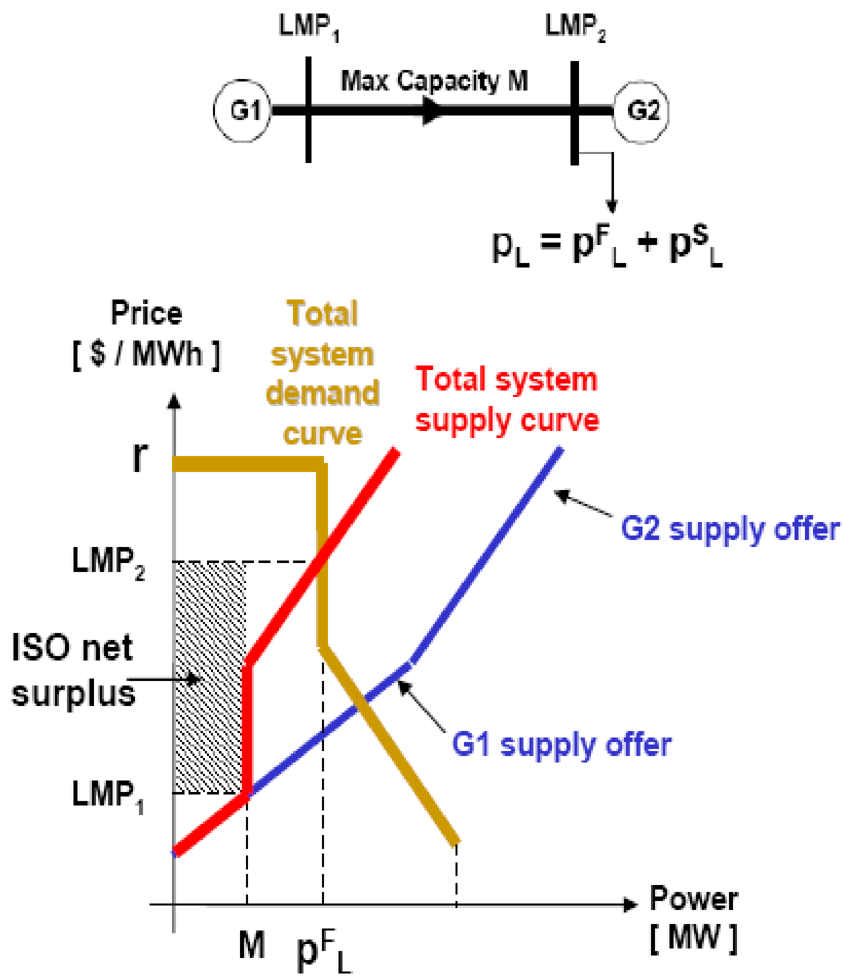
p^F_L = Fixed demand of LSE (in MWs, no price sensitivity)

r = Regulated rate for LSE retail resale of fixed demand

Price = D(p^S_L) : Price-sensitive demand function of LSE

LMP_1 = LMP_2 = ***CMC* Price** if branch limit M is removed

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.

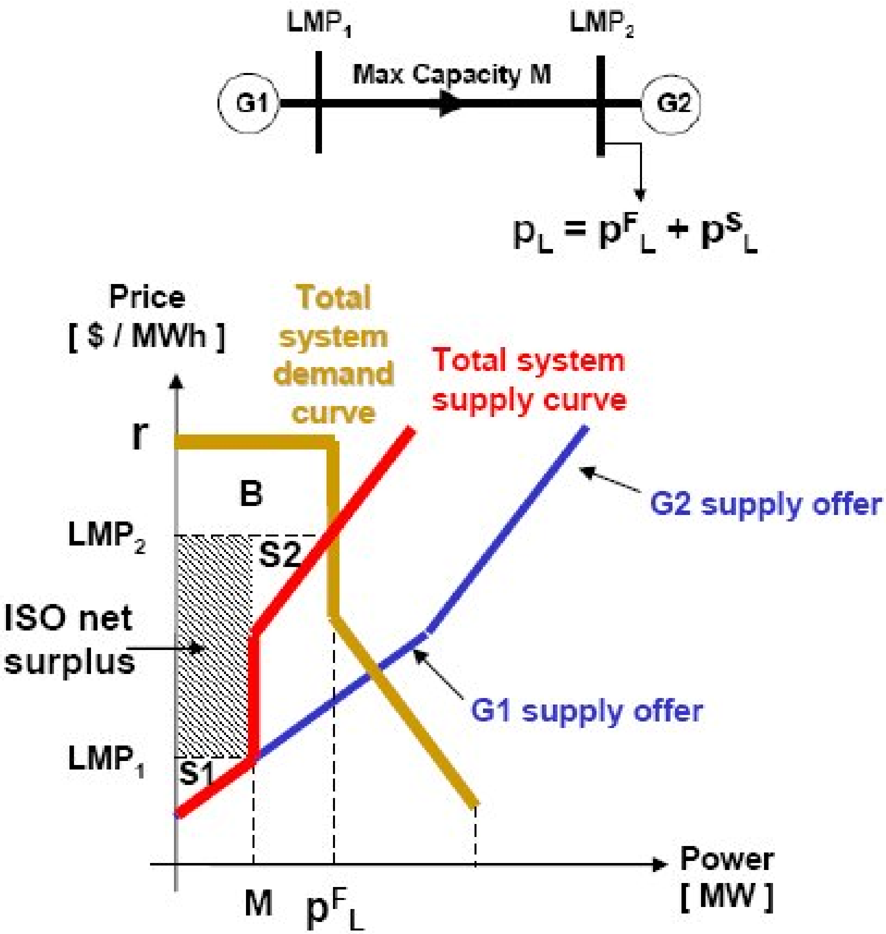
ISO collects difference:

ISO Net Surplus

= [LSE Payments
  – GenCo Revenues]

= $M \times [LMP_2 - LMP_1]$

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**]

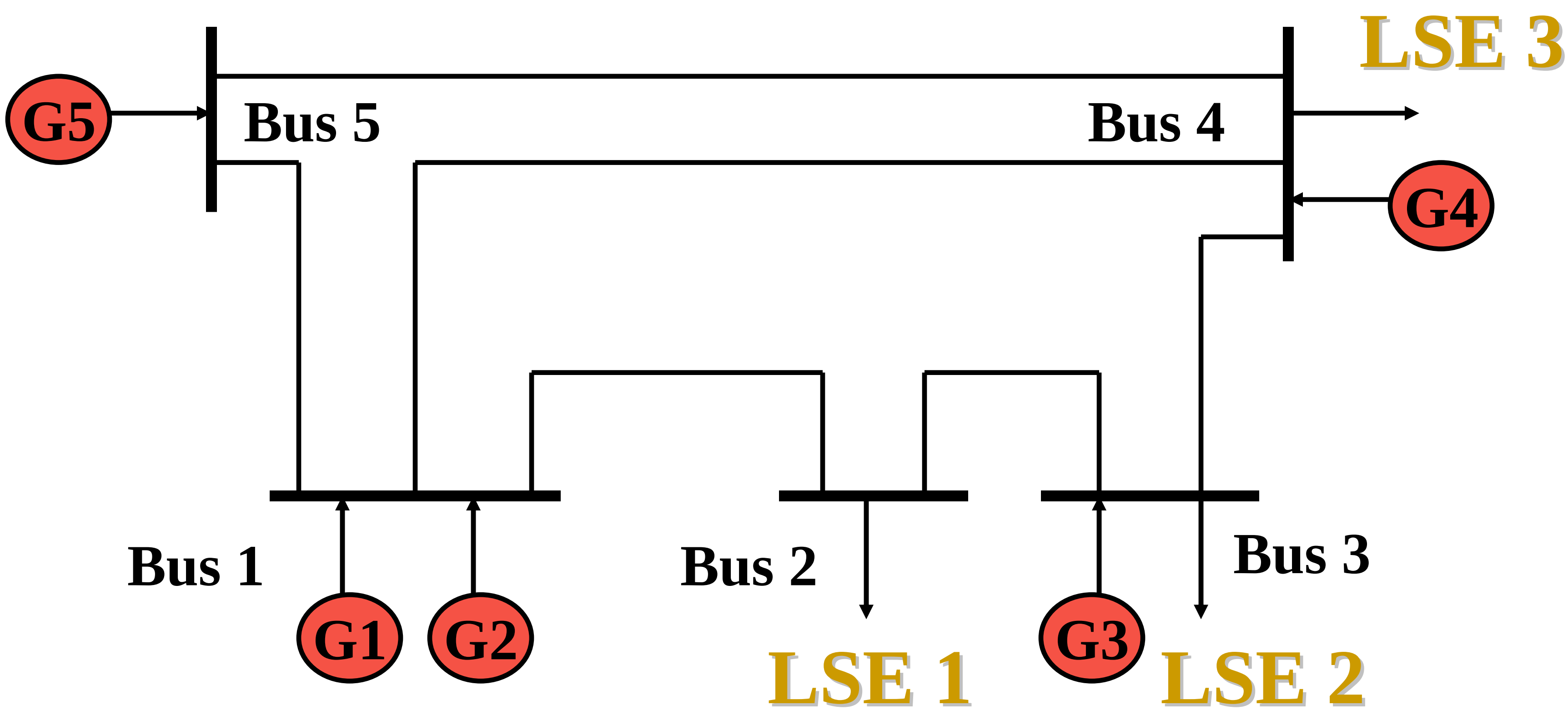
ISO Objective (OPF):

maximize **TNS** subject to

trans/gen 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

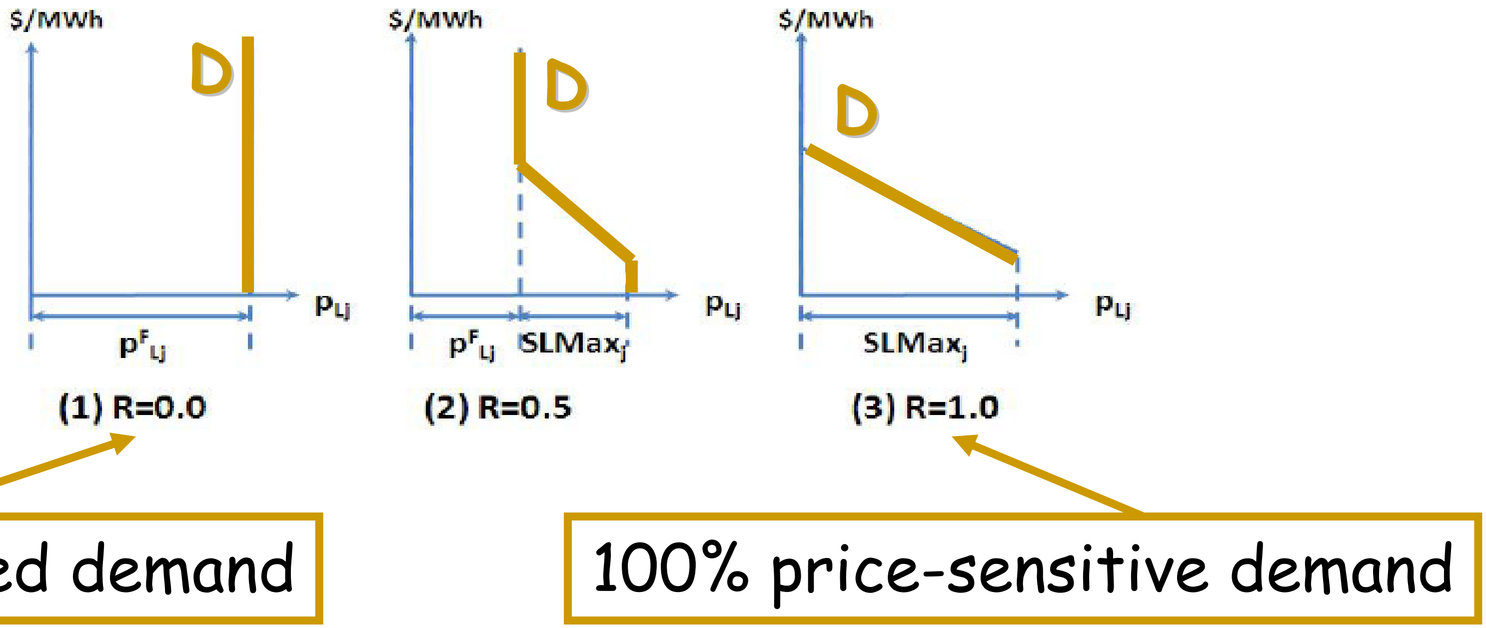


Experimental Control of Relative Demand-Bid Price Sensitivity

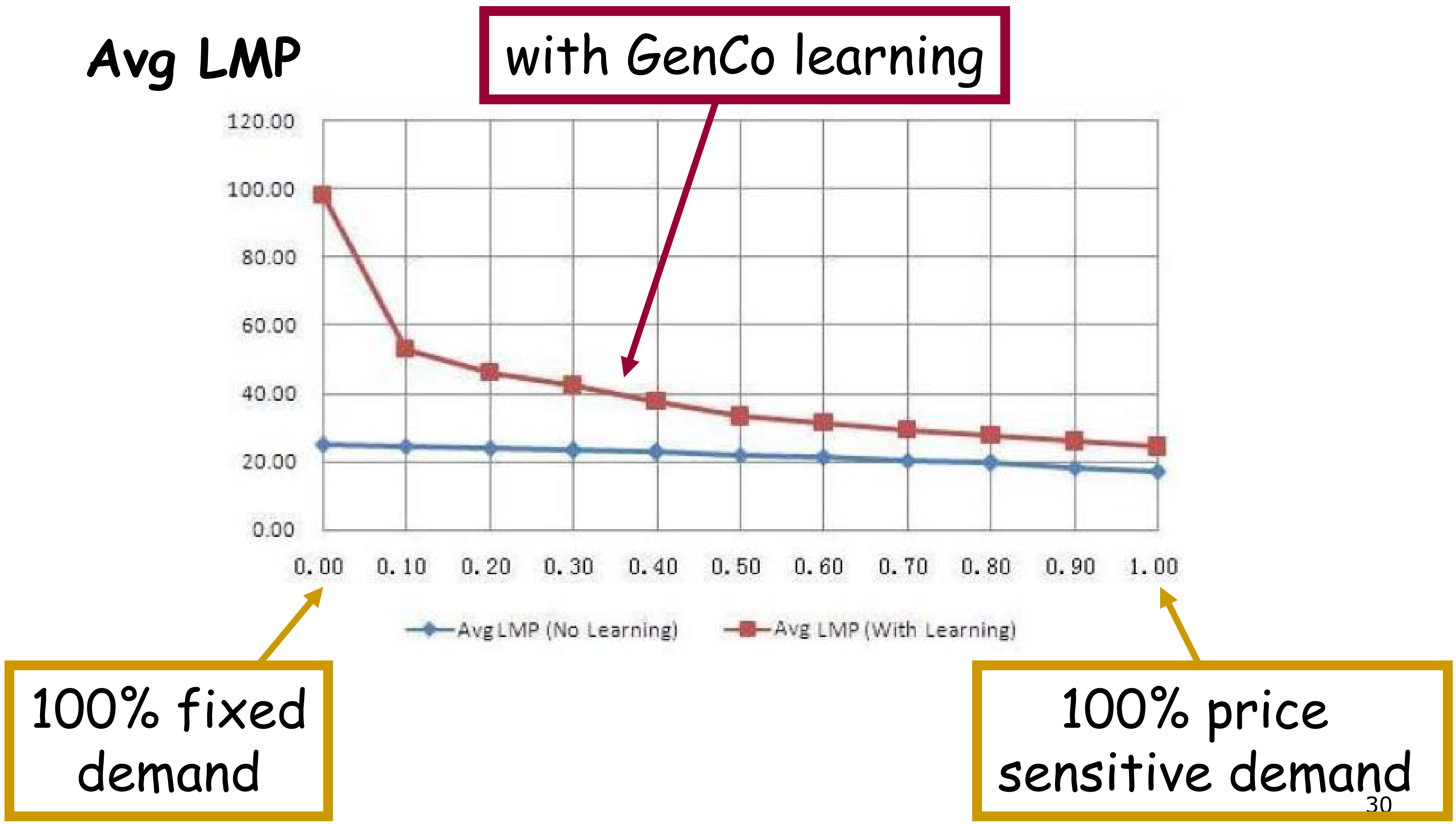
Demand bid for LSE j (MW):

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

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

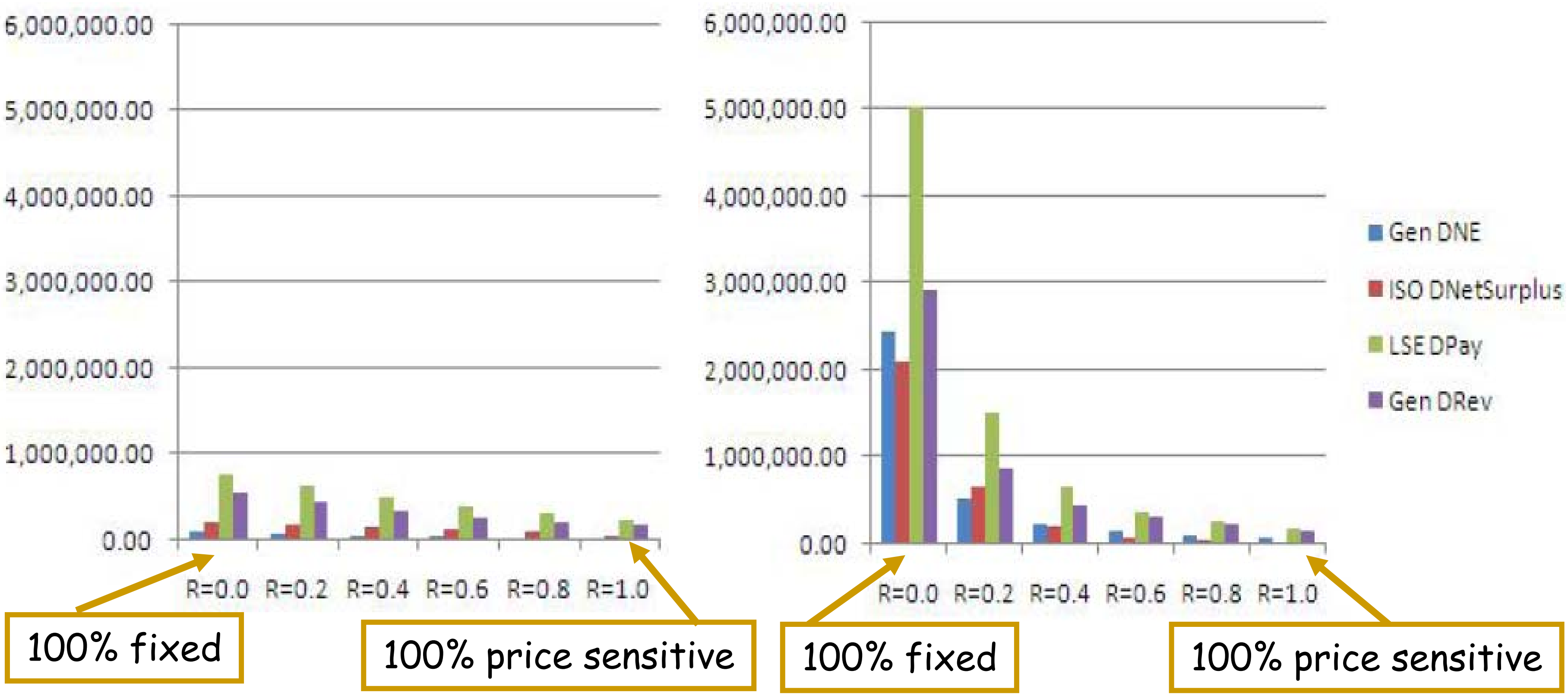


Average LMP Outcomes on Day 1000
(under different learning & demand treatments)



Average ISO Net Surplus Outcomes on Day 1000
(under different learning & demand treatments)

Without Learning **With Learning GenCos**



= GenCo Net Earnings = ISO Net Surplus

ISO Net Surplus, ME, 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 organized as Double Auctions (DAs)

- Standard DA theory does not cover efficiency/welfare implications of net surplus extractions by third parties, ***in particular by auction managers (e.g. by ISOs).***

- ISO net surplus extraction ***increases*** in circumstances ***unfavorable*** to market efficiency (hence social welfare).

- Transparent reporting & oversight of ISO operations are desirable since ISO financial incentives are not fully aligned with social efficiency/welfare objectives.

On-Line Resources

- **Presentation Slides**
  www.econ.iastate.edu/tesfatsi/AuctionTalk.LT.pdf

- L. Tesfatsion, **Auction Basics for Wholesale Power Markets: Objectives & Pricing Rules** (IEEE PES GM Proceedings, July 2009)
  www.econ.iastate.edu/tesfatsi/AuctionBasics.IEEEPES2009.LT.pdf

- H. Li & L. Tesfatsion, "**ISO Net Surplus Extraction in Restructured Wholesale Power Markets**" (ISU Econ WP # 09015, July 2009)
  www.econ.iastate.edu/tesfatsi/ISONetSurplus.WP09015.pdf

- **AMES Test Bed Homepage** (Code/Manuals/Publications)
  www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm