

# Designing an Electricity Market that Benefits Consumers

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# Outline of Talk

- Market Design Problem—What is it?
- Constraints Facing Market Designer
  - Market Power by Generation Unit Owners
- Measuring Market Power in Electricity Markets
  - Role of Congestion Management in Limiting Market Power
- Limiting Ability of Firms to Exercise Market Power
  - Role of Forward Markets
  - Role of Price-Responsive Demand
  - Role of Transmission Network

# Theory of Market Design

- Market Design Requires Solving Principal-Agent Problems at Multiple Levels
- Principal-Agent Problem
  - Principal designs payment scheme which causes agent to act to maximize principal's payoff function
  - Agent behaves to maximize its own payoff function once payment scheme is set
- Market Designer = Principal
  - Usually government and/or regulator
  - Agents = Firms and consumers in market
    - Owner of Firm = Principal
    - Management of Firm = Agent

# Principal/Agent Problem

- $W(x,s)$  = Payoff of Principal (regulator or government)
  - $x(a,s)$  = observable market outcomes  $x$
  - $s$  = state of world  $s$  (level of market demand)
- $V(a,y,s)$  = Payoff of Agent (firm)
  - $a$  = actions (bids, maintenance, employment, fuel use decisions)
  - $y(x)$  = compensation function set by principal (how firms are paid for actions they take)
- Usually assume that Principal
  - Cannot observe all actions  $a$  or true state of world  $s$
  - Can observe  $x(a,s)$  outcome that depends on  $a$  and  $s$

# Principal-Agent Theory

- Principal's problem is to choose function,  $y(x)$ , to maximize  $E_s[W(x,s)]$  subject to
  - (1) Individual rationality of agent--agent will choose  $a$  to maximize  $V(a,y(x),s)$  or its expectation given  $y(x)$  and  $s$
  - (2) Participation constraint-- $y(x)$  must allow agent to achieve reservation payoff or expected payoff  $V^*$
- Regulator must recognize that once  $y(x)$  is set, agent will choose  $a$  to maximize its payoffs
- Regulator must set  $y(x)$  to allow agent to achieve at least reservation payoff  $V^*$

# Market Power = Major Market Design Challenge

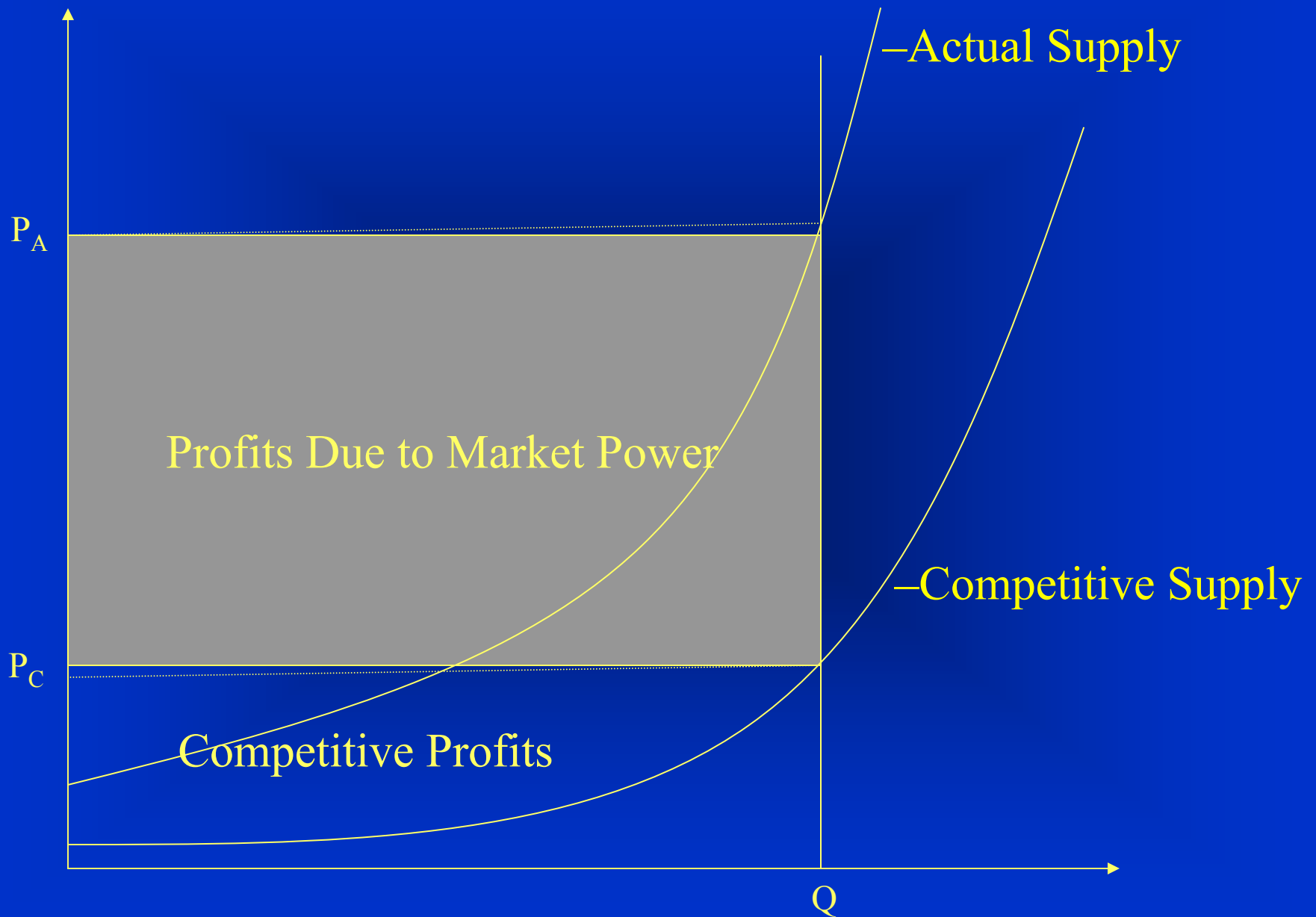
- Measure of market power
  - Extent that market prices are in excess of perfectly competitive ideal
  - Standard measure used in markets for all other products
  - Provides assessment of the efficiency of the market reflecting production costs in market prices
- Many other measures, but this is bottom line

# Compute Measures of Market Power from 6/1/98 to 12/31/00

- 1) Extent of market power exercised in market on hourly basis
  - a) Compare actual quantity-weighted average price to competitive benchmark weighted average price over given time horizon
  
- 2) Account for increase in competitive benchmark prices due to
  - a) Input fuel price increases in 2000 versus 1999 and 1998
  - b) Emission cost increases in 2000 versus 1999 and 1998

See Borenstein, Bushnell, and Wolak (2002) “Measuring Market Inefficiencies in California Re-structured Electricity Market” *American Economic Review*, December, for detailed methodology.

# Competitive Profits versus Profits Due to Market Power



# Summary of Market Performance from April 1998 to April 2000-Competition Works

- 1) Market power historically exercised during months of August to September
- 2) Little market power exercised during months of October to April
- 3) For one year period October 1998 to September 1999 little market power  $P(\text{actual}) - P(\text{comp})$  approximately equal to zero

# Summary of Market Performance from May 2000 to June 2001--Competition fails

- 1) Extraordinary amount of market power exercised  
from June 2000 to June 2001
- 2) Average market power markup  $P(\text{act}) - P(\text{comp})$  for  
Calendar year 1999--\$4/MWh  
Average  $P(\text{act}) = \$33/\text{MWh}$   
Calendar year 2000--\$45/MWh  
Average  $P(\text{act}) = \$110/\text{MWh}$   
January 2001 to June 2001--More than \$100/MWh  
Average  $P(\text{act})$  more than \$200/MWh

# California's Flawed Market Design?

For Nodal, Zonal, and Single-Price Markets, Compare Relationship between

$$\text{Hourly Value of Lerner Index} = \frac{(P(\text{act}) - P(\text{comp})) / P(\text{act})}{\text{(Hourly Demand for Capacity in Control Area)} / \text{(Capacity in Control Area)}}$$

Time Period = May 1999 to December 1999

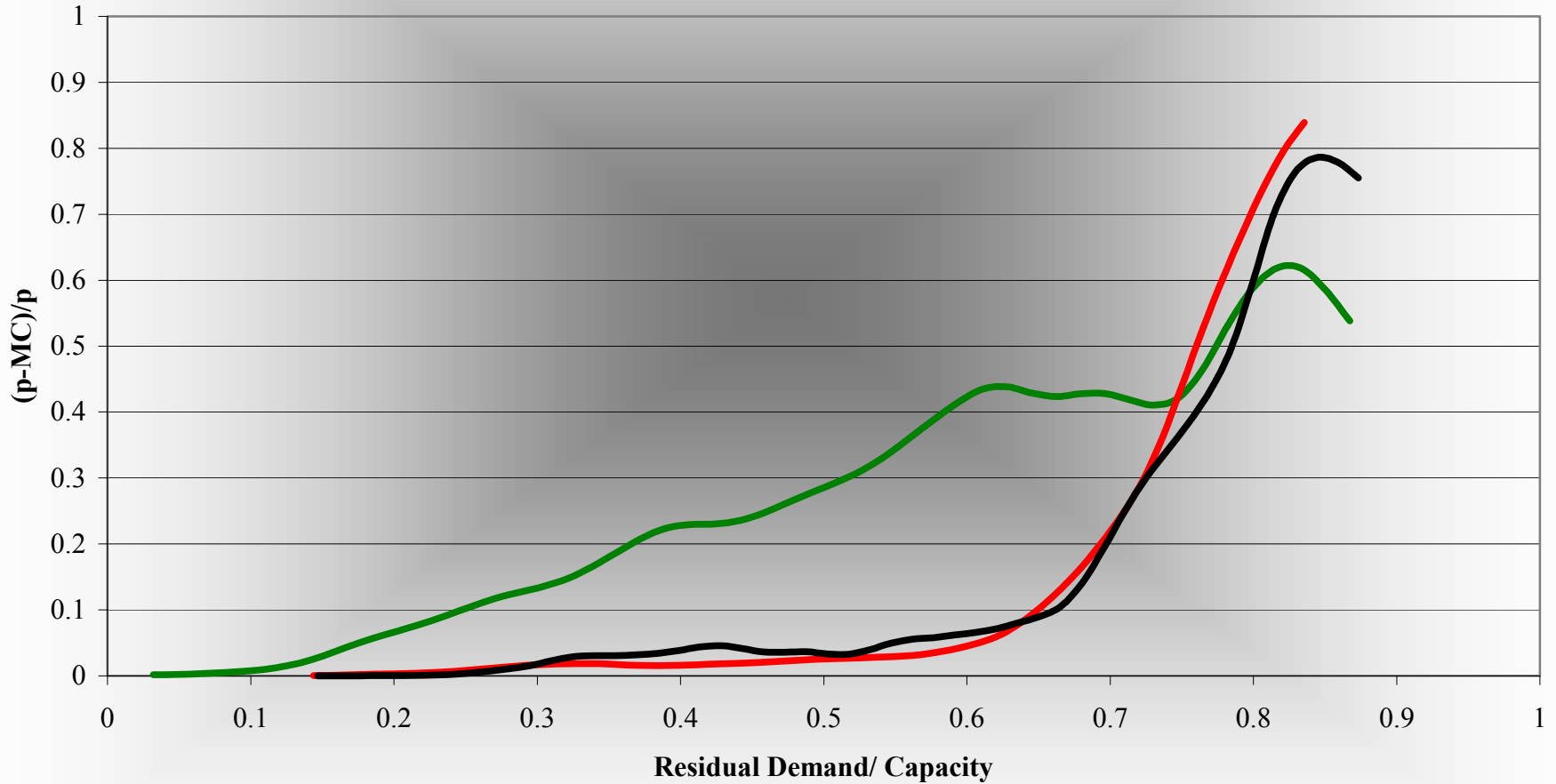
Mansur (PJM)--Nodal

Bushnell & Saravia (New England)--Single Price

Borenstein, Bushnell, and Wolak (CA)--Zonal

# Kernel Regression of Lerner Index vs. Capacity Ratio May - December 1999

Cal NE PJM



**Source: Bushnell and Savaria (2002)**

# California's Flawed Zonal Market Design?

All electricity markets susceptible to exercise of market power

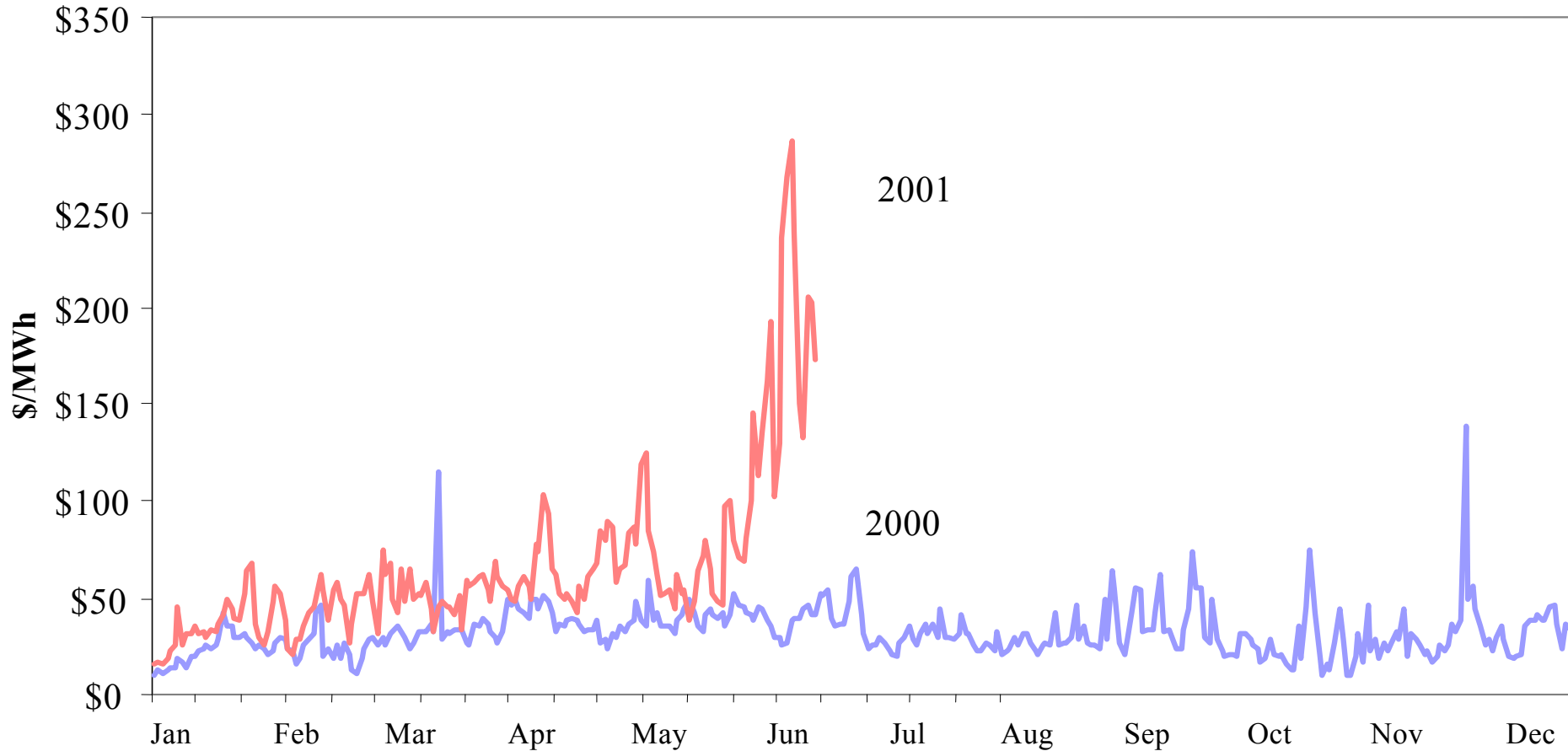
Overall amount of market power exercised during this time period highest in PJM market (nodal market)

Least amount of market power exercised during this period was in ISO-NE, single price market

Congestion management method does not appear to impact ability of firms to exercise market power.

# Guess the Locational Pricing Scheme?

## Average Daily Wholesale Price



# Guess the Locational Pricing Scheme?

The wholesale price is 5 times its usual level

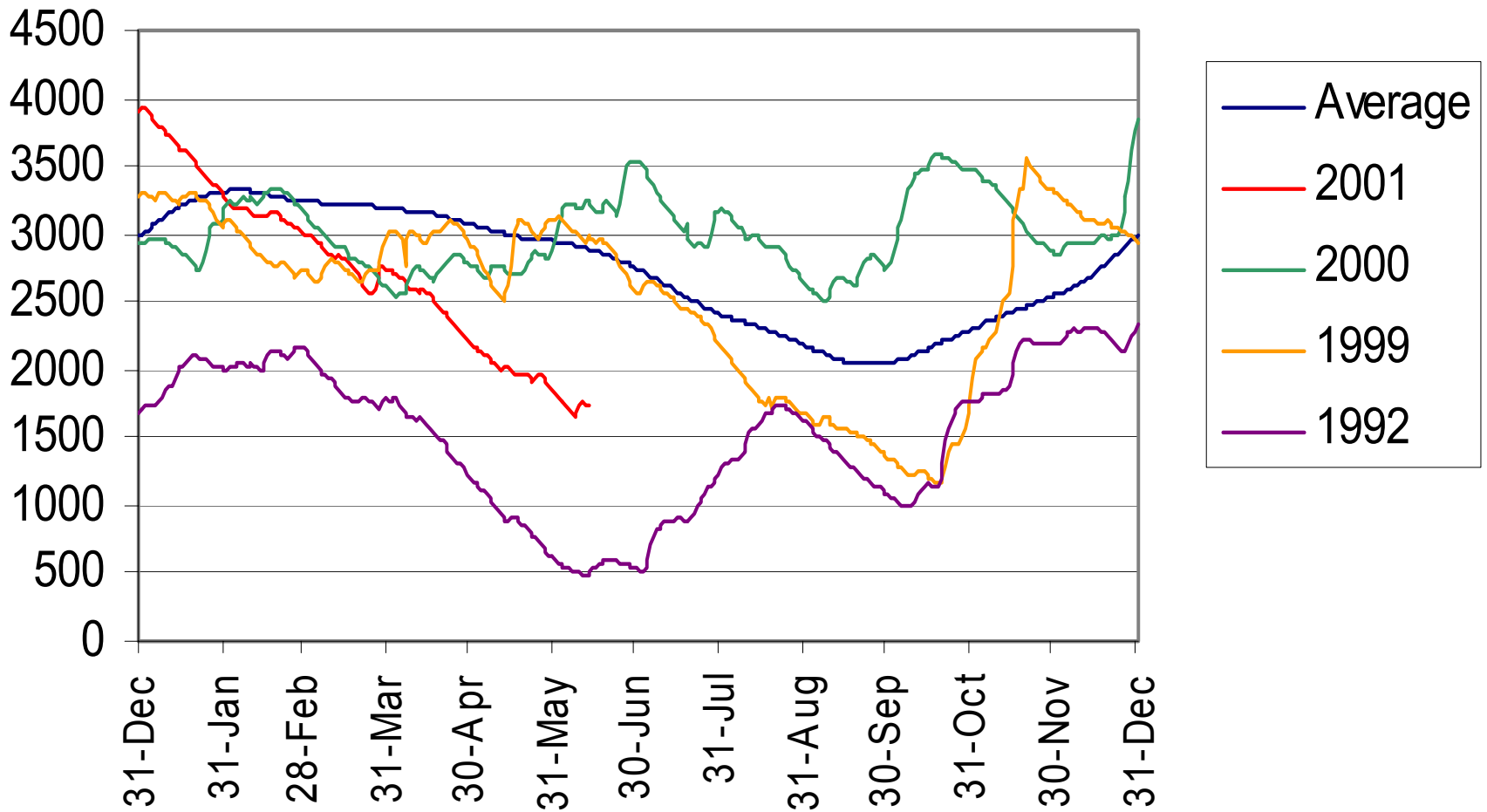
Daily average normally \$40-50 per MWh

Averaging around \$200 per MWh in June

Sounds like California, but it's the wrong  
year!

# New Zealand's Flawed Nodal Pricing Scheme?

## New Zealand Hydro Storage



# Cause of CA and NZ Market Meltdowns

- Insufficient hedging of spot price risk by California load-serving entities and significantly less imports available to California in 2000 (relative to '98 and '99) was major cause of “crisis”
  - Generators had virtually no forward market obligations to California load-serving entities which considerably enhanced their ability and incentive to exercise market power in spot market—see Wolak (2003) “Measuring Unilateral Market Power in Wholesale Electricity Markets: California 1998 to 2000” available on web-site
- For similar reasons, market meltdown occurred in New Zealand, which has FERC’s recommended spot market design
  - New Zealand runs a nodal market design
  - System very dependent on hydroelectric capacity
  - Insufficient forward contracts held by load-serving entities
  - Concentration of fossil-fuel capacity ownership

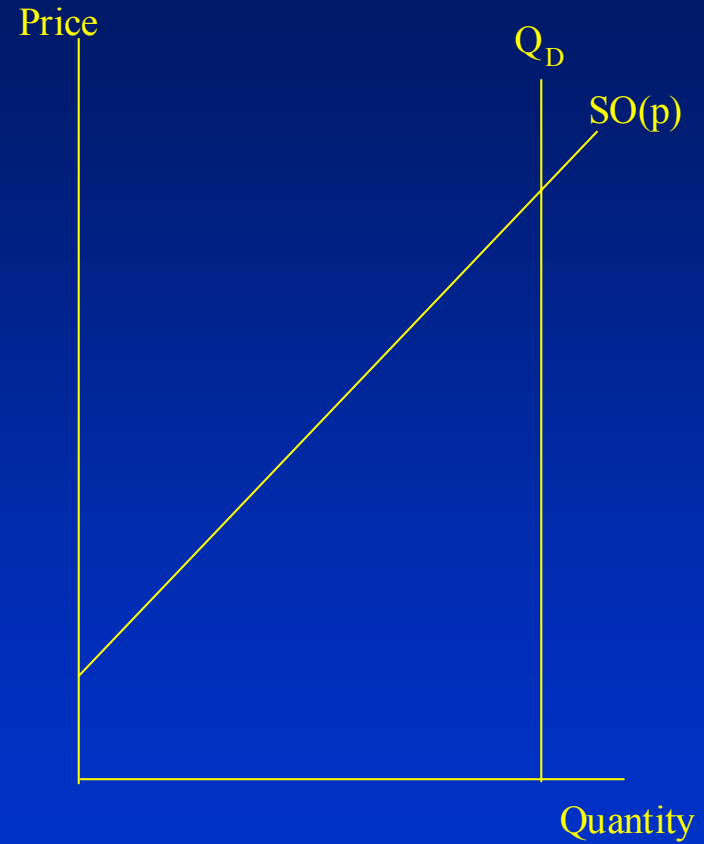
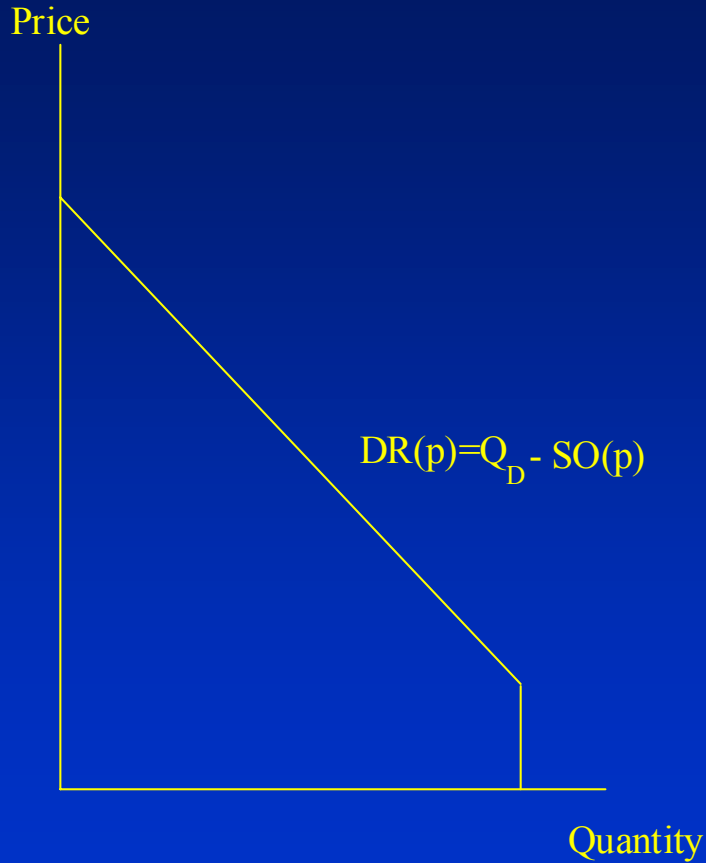
# Bidding in Competitive Markets

- First Step in Market Design Process
  - Understanding how firms bid to maximize profits under given set of market rules,  $y(x)$
  - How do firms exercise their unilateral market power
- Allows Market Designer to define constraint set it faces in maximizing its payoff function
  - Firms will maximize profits given market rules
    - Individual Rationality
  - Firm must be expect to earn return sufficient for it to participate in market
    - Participation Constraint

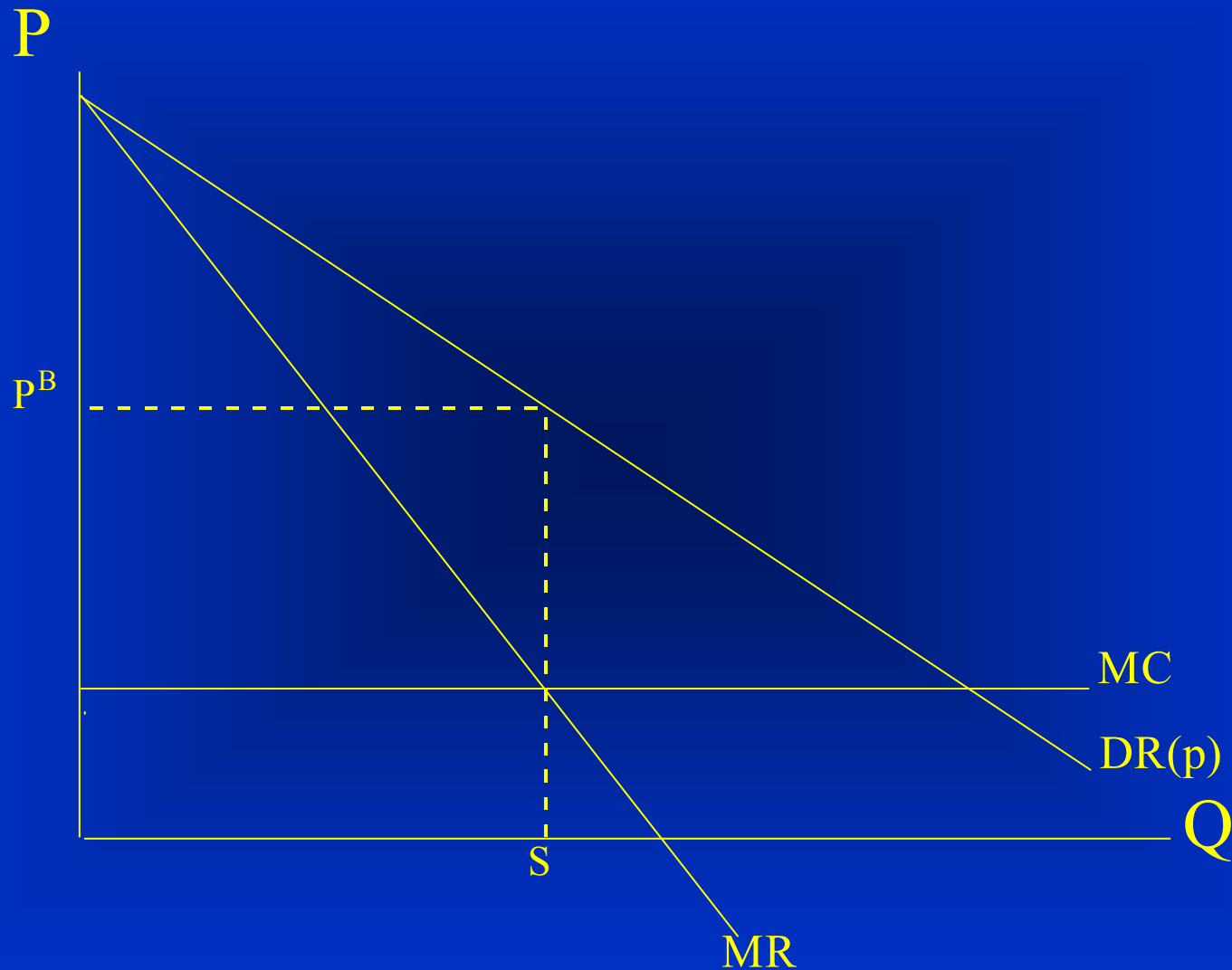
# Bidding in Competitive Markets

- Simple model of profit-maximizing bidding behavior in competitive market
- $Q_{id}$ : Total market demand in load period  $i$  of day  $d$
- $SO_{id}(p)$ : Amount of capacity bid by all other firms besides Firm A into the market in load period  $i$  of day  $d$  as a function of market price  $p$
- $DR_{id}(p) = Q_{id} - SO_{id}(p)$ : Residual demand faced by Firm A in load period  $i$  of day  $d$ , specifying the demand faced by Firm A as a function of the market price  $p$
- $\pi_{id}(p)$ : Variable profits to Firm A at price  $p$ , in load period  $i$  of day  $d$
- MC: Marginal cost of producing a MWH by Firm A

# Residual Demand Curve faced by Firm



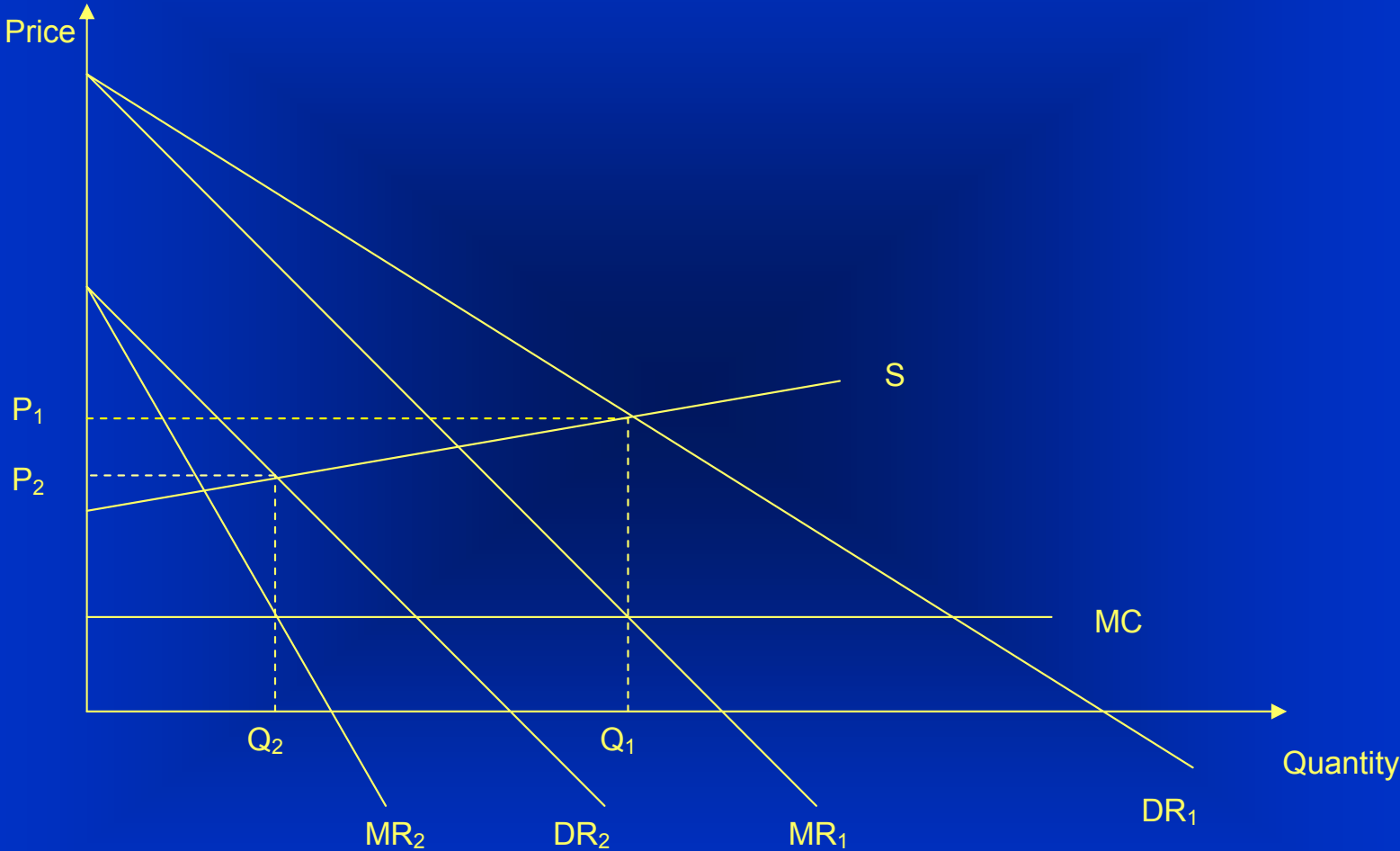
# Bid to Maximize Profits Subject to Residual Demand



Profit-maximizing behavior implies a profit-maximizing price above marginal cost

- Residual Demand Curve unknown at time generator submits bids
  - Demand uncertainty
  - Uncertainty about actions of other suppliers
- Optimal bid curve depends on distribution of elasticities of residual demand function

# Bid to Maximize Expected Profits



# Market Design = Limiting Market Power of Firms

- Make residual demand curves perceived by all unit owners as elastic as possible
  - Generators facing infinitely elastic residual demand curve perceive themselves as being unable to impact the market price by their bids
  - Optimal strategy for generation unit owner facing infinitely elastic residual demand curve is to bid marginal cost curve (MC) as willingness to supply curve  $[S(p)]$
  - This will lead to market prices as close as possible to market designer's optimum

# Limiting Market Power of Firm

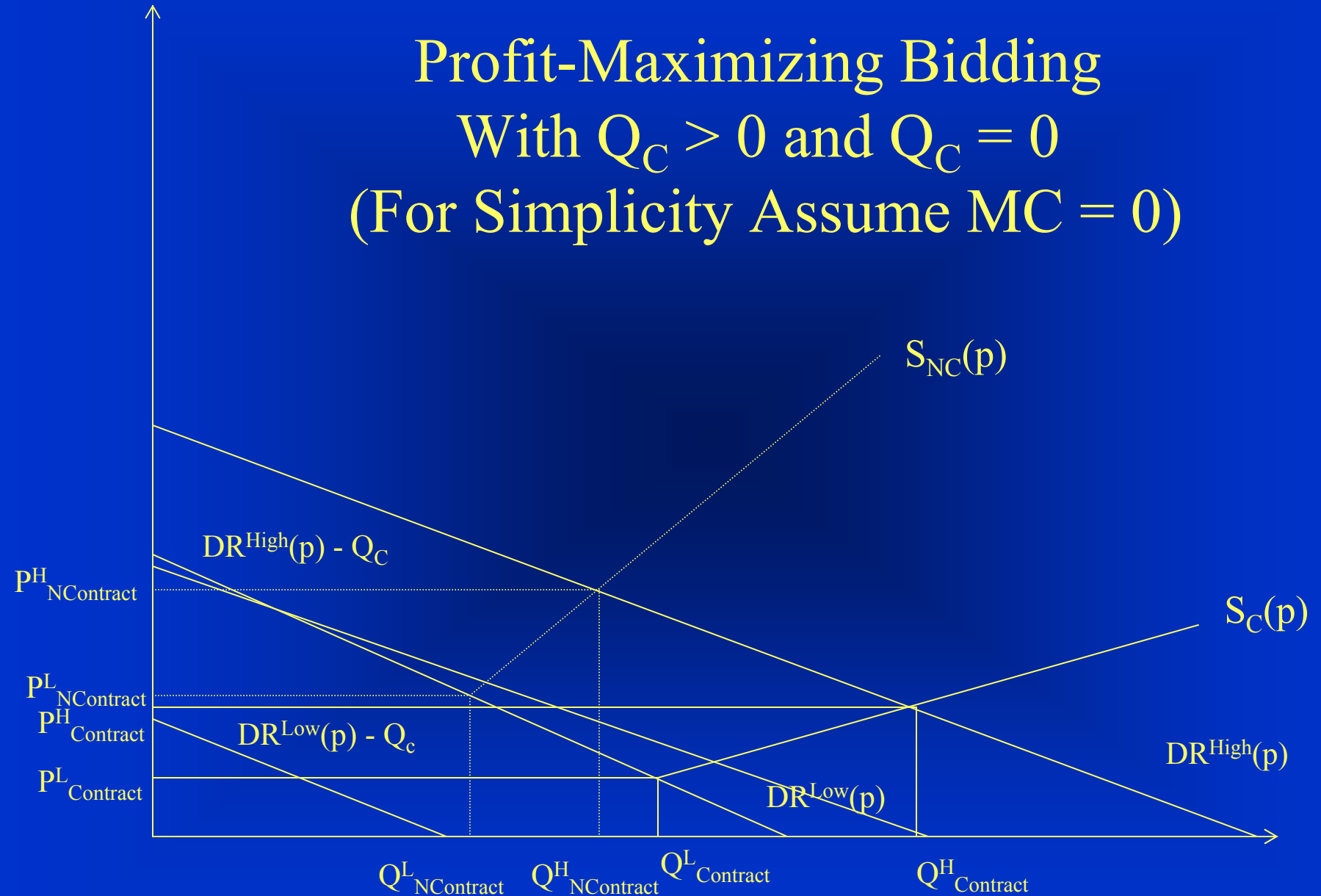
- Market Power problem increasingly more extreme the closer market gets to real-time
  - Set of potential competitors increases as time between price negotiation and delivery increases
  - Only those plants operating with unloaded capacity can deliver energy in real-time
- Forward Financial commitments make firm bid more aggressively in spot market
  - This makes other firms want to bid more aggressively

# Limiting Market Power of Firm

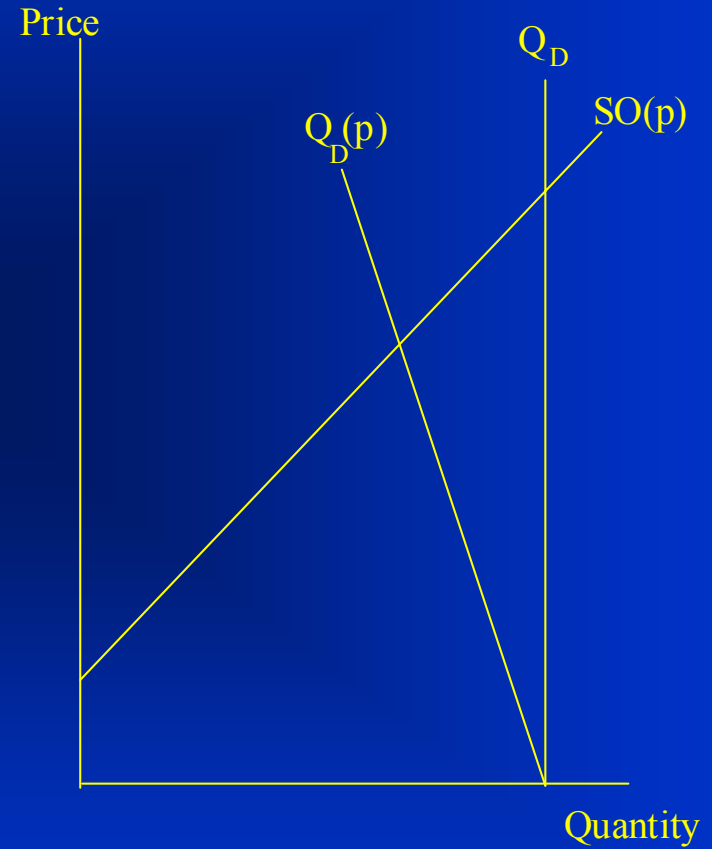
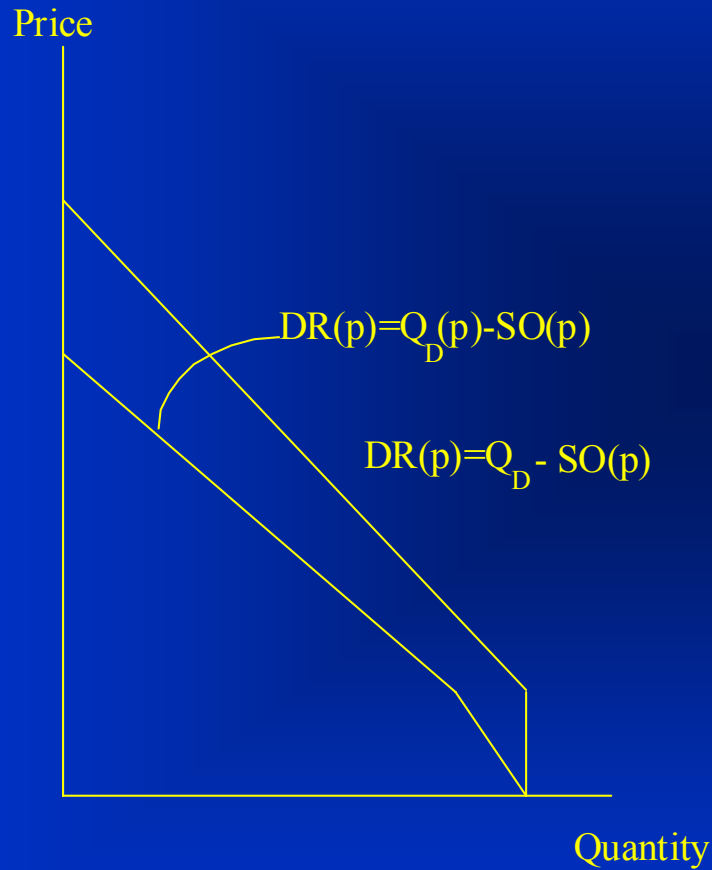
- Price Responsive Demand makes residual demand curves perceived by all unit owners more elastic
- Transmission upgrades to face all unit owners with more elastic residual demand curves
  - Economic reliability of transmission network versus Engineering Reliability of transmission network

# Profit-Maximizing Bidding

With  $Q_C > 0$  and  $Q_C = 0$   
 (For Simplicity Assume  $MC = 0$ )



# Benefits of a Price Responsive Demand



# Transmission Network and Market Power

- Transmission networks were built for former vertically integrated monopoly regime
  - Built to take advantage of economies to scope between transmission and generation to meet local energy needs
  - Integrated resource planning by vertically integrated monopolist considers both local generation and transmission to find least-cost solution to serve additional load
  - Transmission capacity across control areas of vertically integrated monopolists built for Engineering Reliability
    - Sufficient transmission capacity so imports could be used to manage large temporary outages within control area
    - Few examples where transmission capacity was built to facilitate significant across-control-area electricity trade--California/Oregon

# Transmission Network and Market Power

- “Over-investment” in transmission capacity relative to engineering reliability concerns can benefit market
  - Economically reliable transmission network requires far greater inter-connection capacity than technologically reliable network
  - Economic reliability--All locations in transmission network are contestable a large fraction of the time
  - May need strong incentives to invest early on to overcome initially inadequate network for competition in generation
- Consider case that “over-invest” in transmission capacity to increase prices by \$1/MWh
  - If increased capacity of transmission network results in more competitive wholesale market and average prices fall by \$2/MWh, consumers benefit from upgrade

# Adam Smith on Market Design

- “It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest. We address ourselves, not to their humanity but to their self-love, and never talk to them of our necessities but of their advantages.”

The Wealth of Nations, Book I Chapter II