UNIVERSITY OF CAMBRIDGE | Electricity Policy Research Group

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

The Theory and Application of Supply Function Equilibrium Models to Electricity Markets

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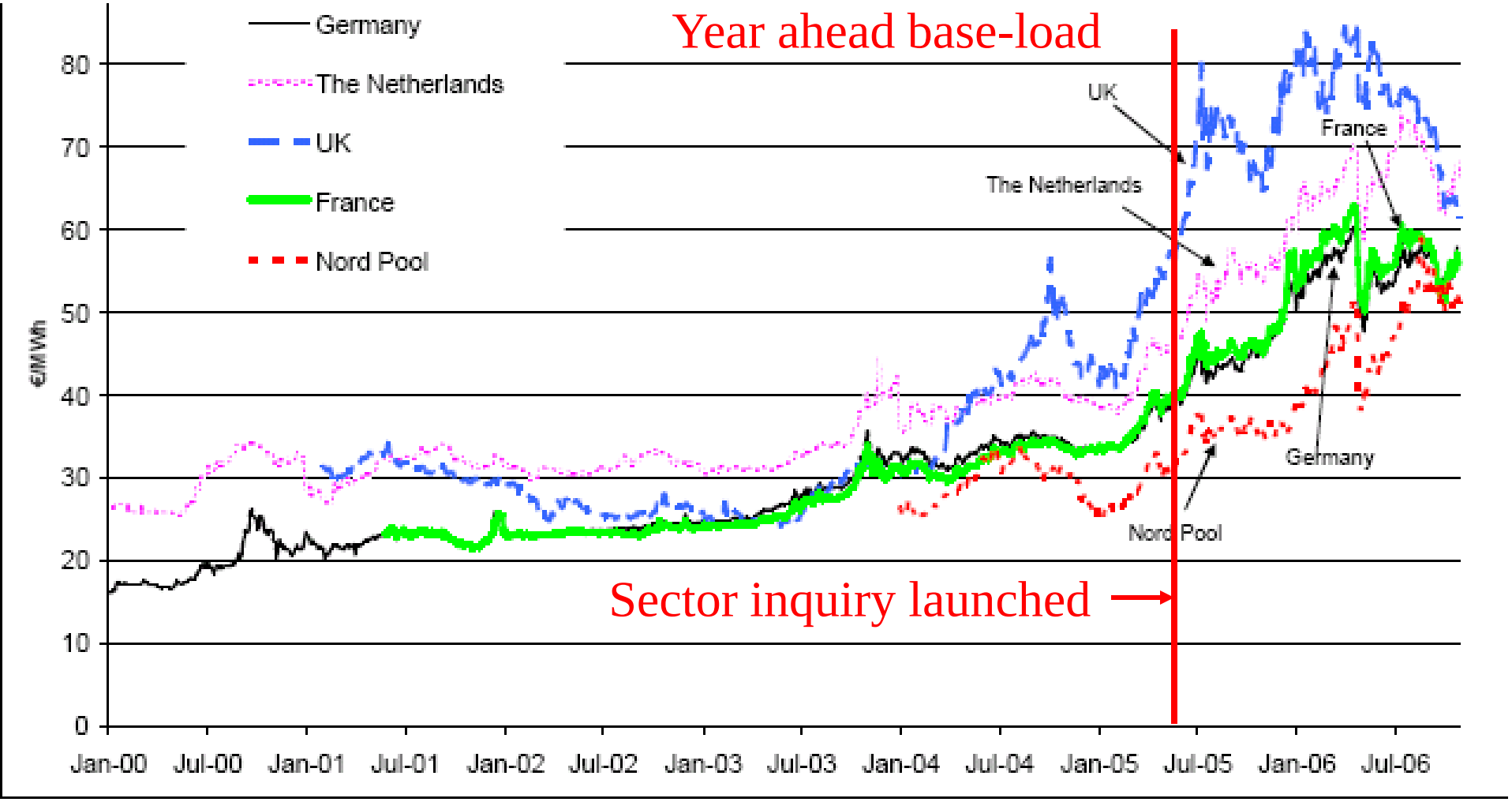
Outline

- Why study supply function equilibria?
  - Testing for market power
  - Testing for collective dominance in electricity
  - predicting effects of liberalisation
- Theory and evidence for SFEs
  - matching theory to reality
  - the role of contracts and entry conditions

Electricity as the benchmark case

Rising prices prompt *Inquiry*?



Source: information received within the scope of the Sector Inquiry from Argus Media, Platts[184], and Nord Pool.

Price determination in electricity markets

- Liberalisation creates wholesale markets
  - day-ahead, balancing, over-the-counter, contract ..
- generators submit ladder of offers
- agents submit bids for demand
- Market operator clears auction at last price

How to model the market equilibrium?

Wholesale electricity markets

- Typically uniform price auctions
  - Separate price determined for each period
  - English Pool: offers day-ahead for 48 half-hours
- Generating costs are common knowledge
- Electricity is a homogeneous good
- Few producers => bid strategically
- Many consumers => price-takers

Modelling market power important

Collective dominance if:

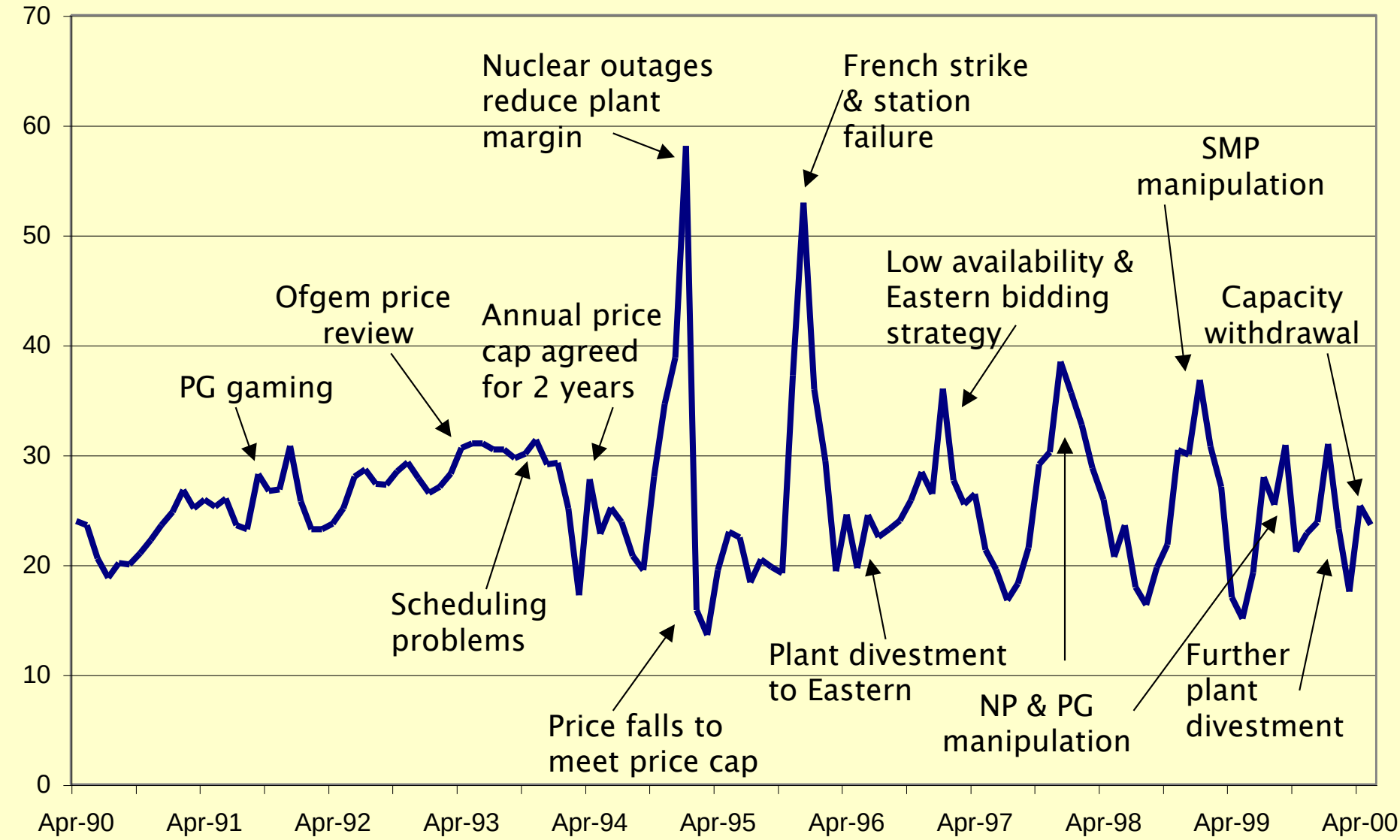
- Market characteristics conducive to tacit coordination, ***and***
- Tacit coordination sustainable:
  - firms lack ability and incentive to deviate, given incentives for retaliation, and
  - Buyers, fringe firms, entrants cannot challenge tacit coordination

Collective dominance criteria

- Markets concentrated, transparent, mature
- Low elasticity of demand
- Homogenous product, similar costs, shares
- Little excess capacity, barriers to entry
- Excess pricing, profit
  - little response to cost fall
  - barriers to switching

Electricity fits this perfectly

Pool prices since vesting

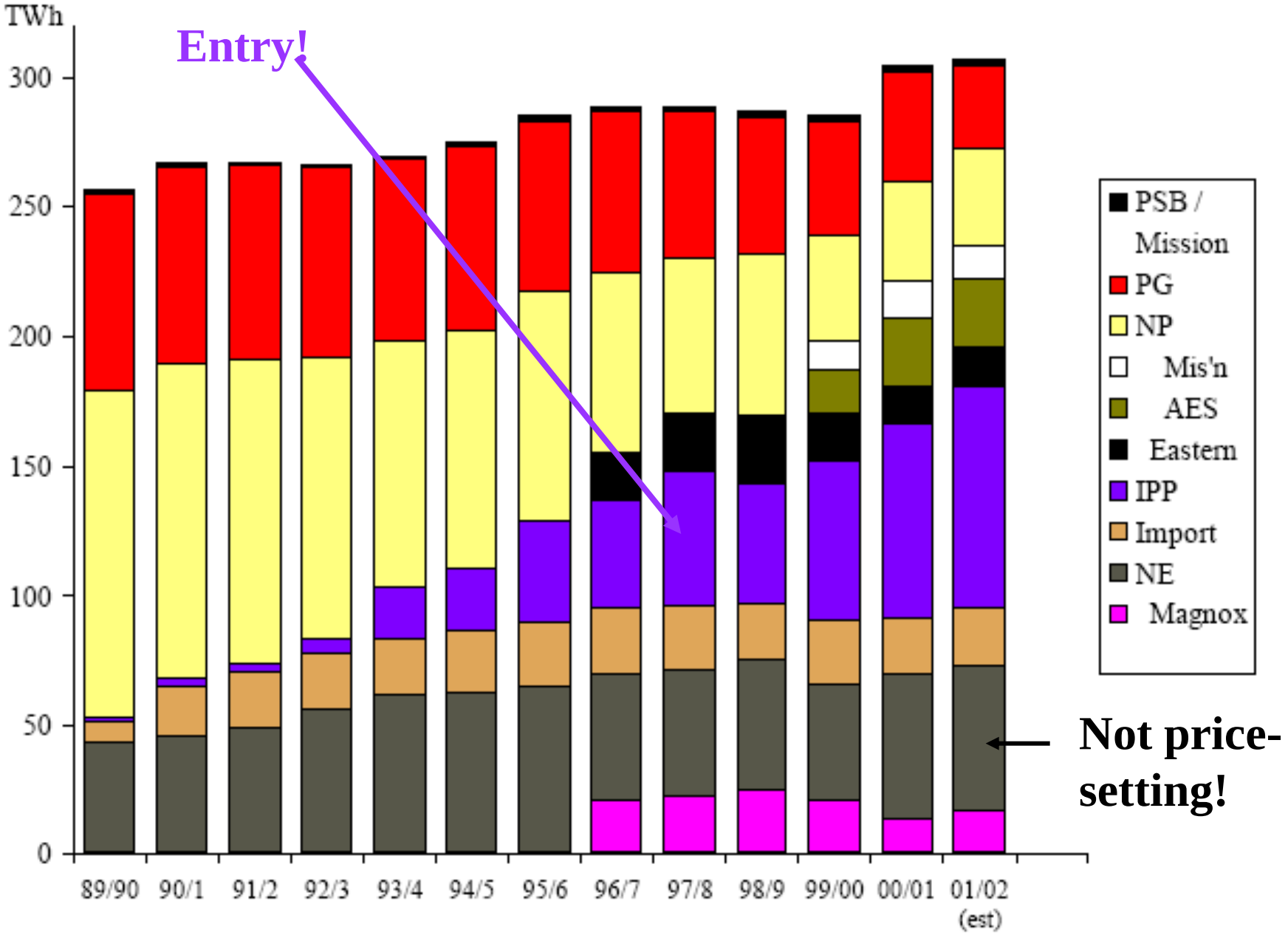


Collective dominance: the Pool

- Markets concentrated, transparent, mature ✓
- Low elasticity of demand ✓
- homogenous product, similar costs, shares ✓
- little excess capacity, barriers to entry **?**
- excess pricing, profit ✓
  - little response to cost fall, ✓
  - barriers to switching **??**

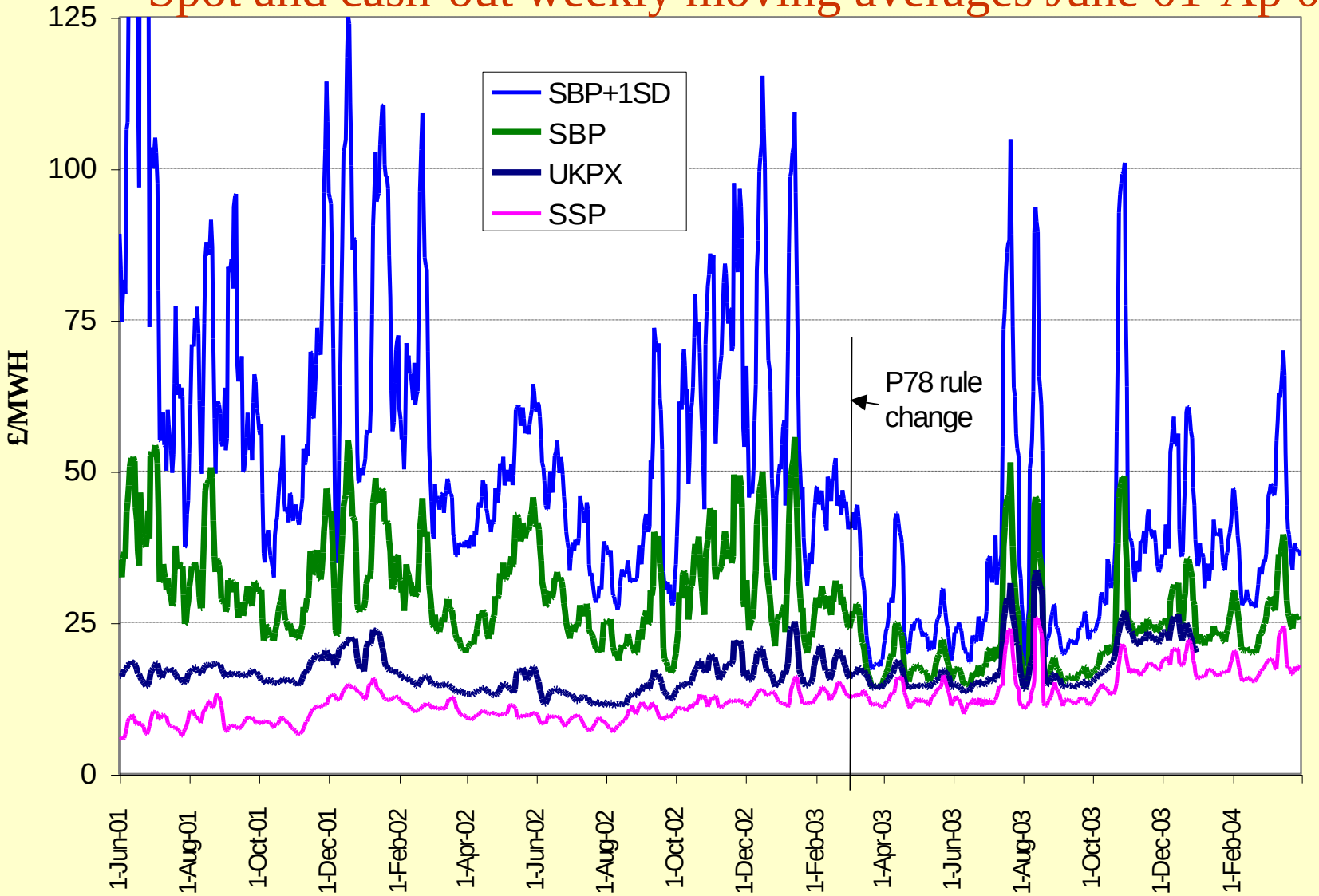
But how to test for tacit collusion?

Generation in England and Wales



Electricity prices are volatile!

Spot and cash-out weekly moving averages June 01-Ap 04



Modeling electricity spot markets

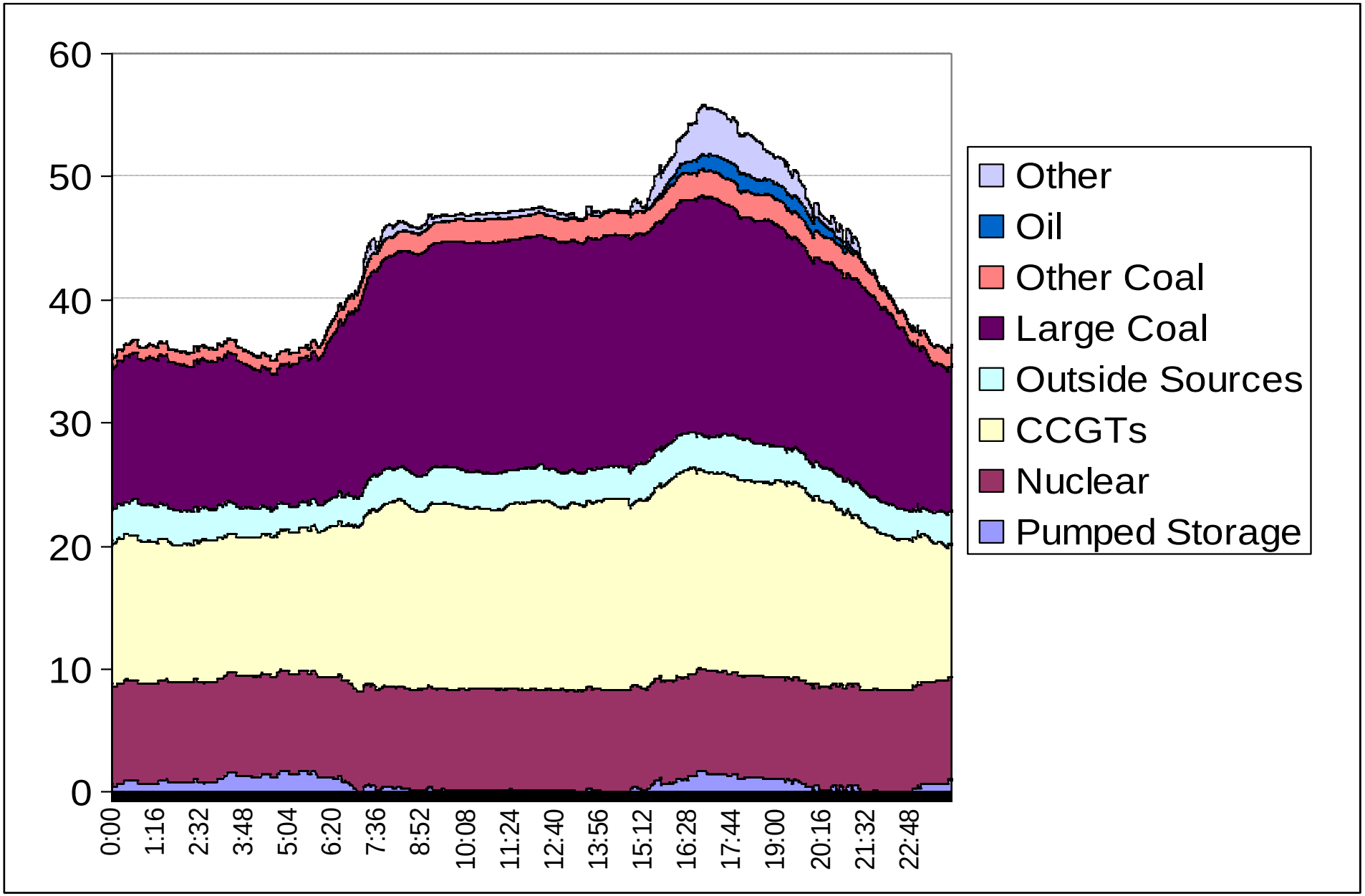
- Demand varies over day
  - and plant can fail suddenly
- MC of different plant varies substantially

  => different plant at margin
- Capacity costs need to be recovered
  - if LF = 10%, capacity cost = 5 times MC

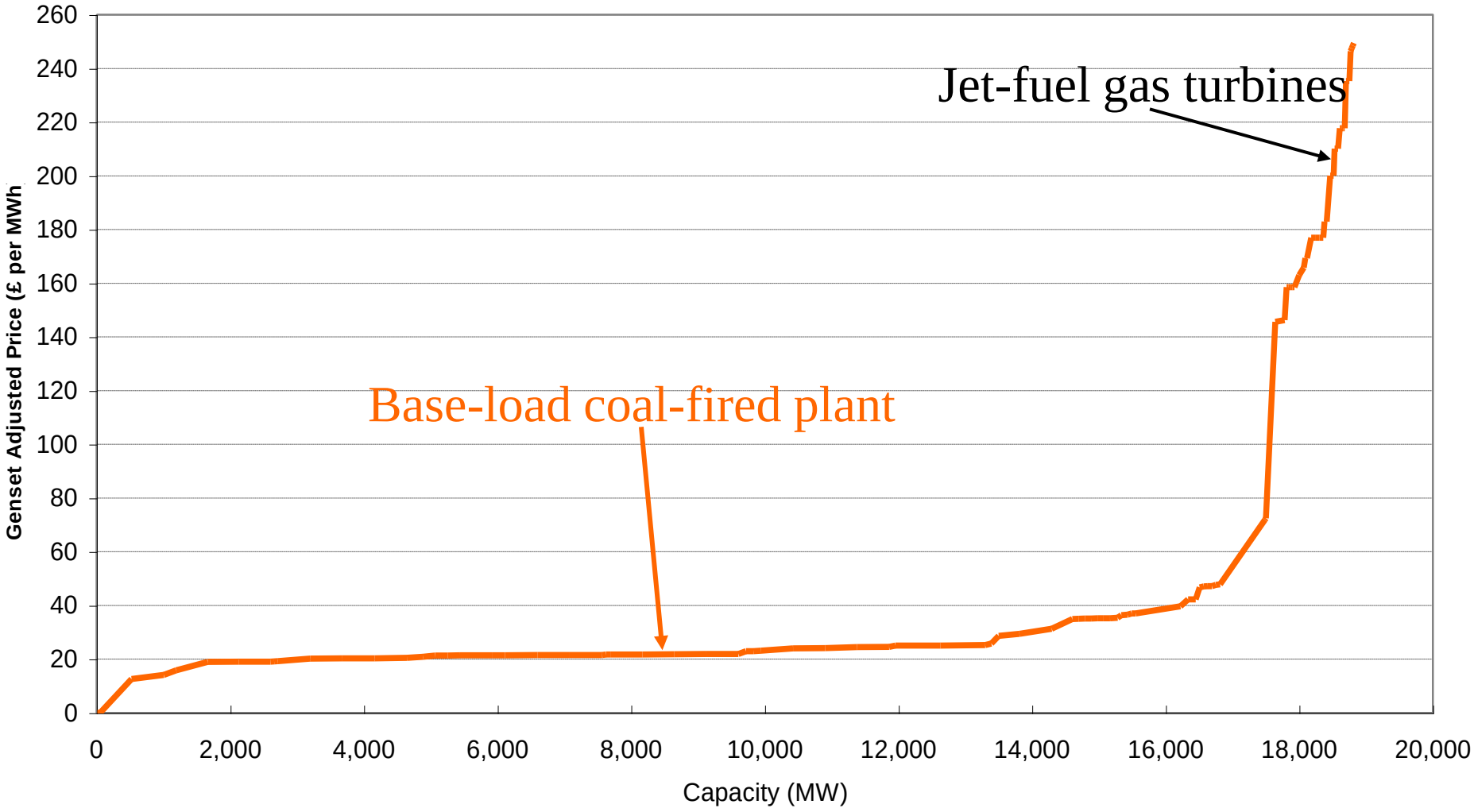
=> Prices can vary dramatically over day

Supply function must cope with volatility

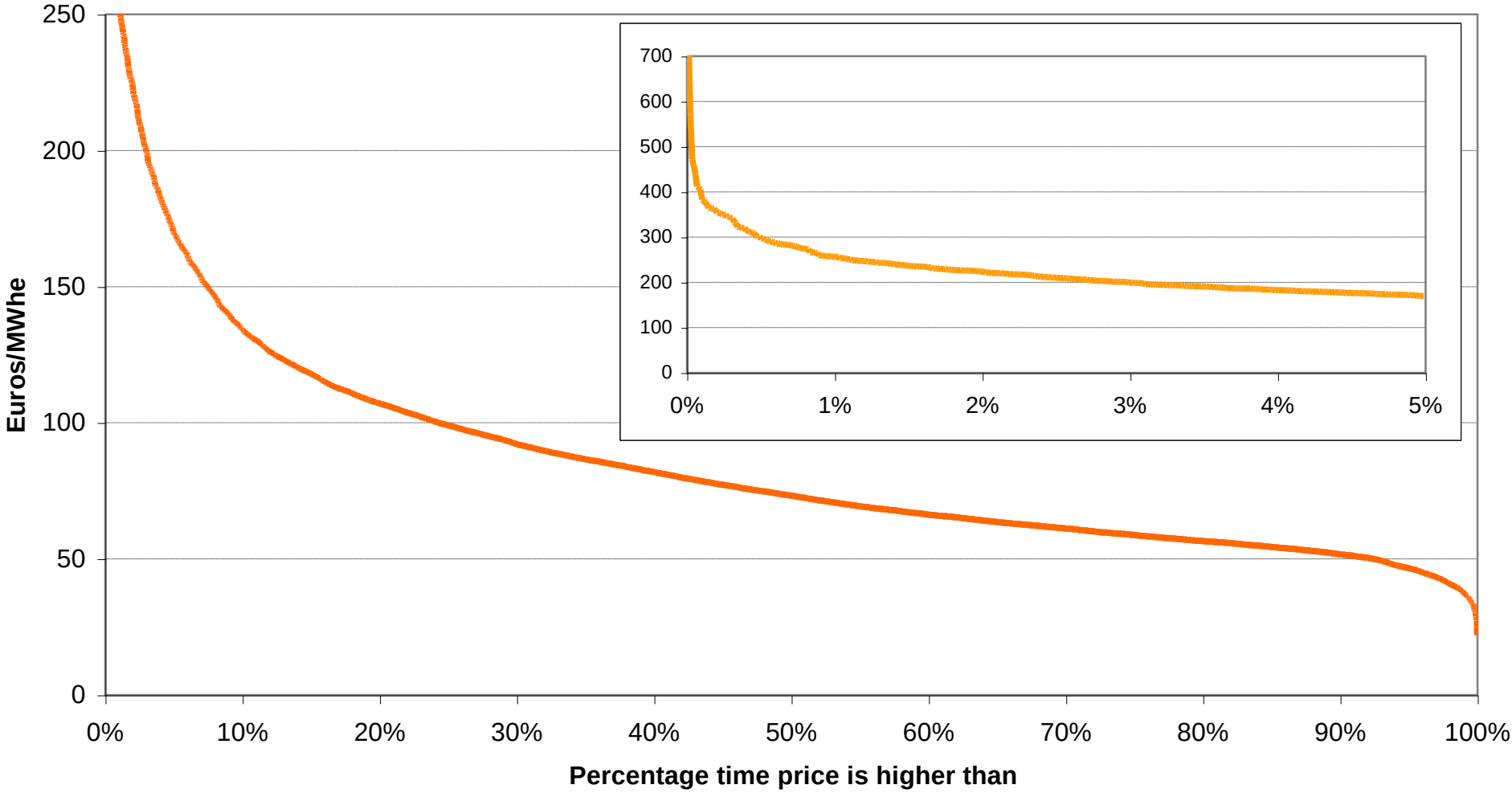
Load profile Dec 10 2002



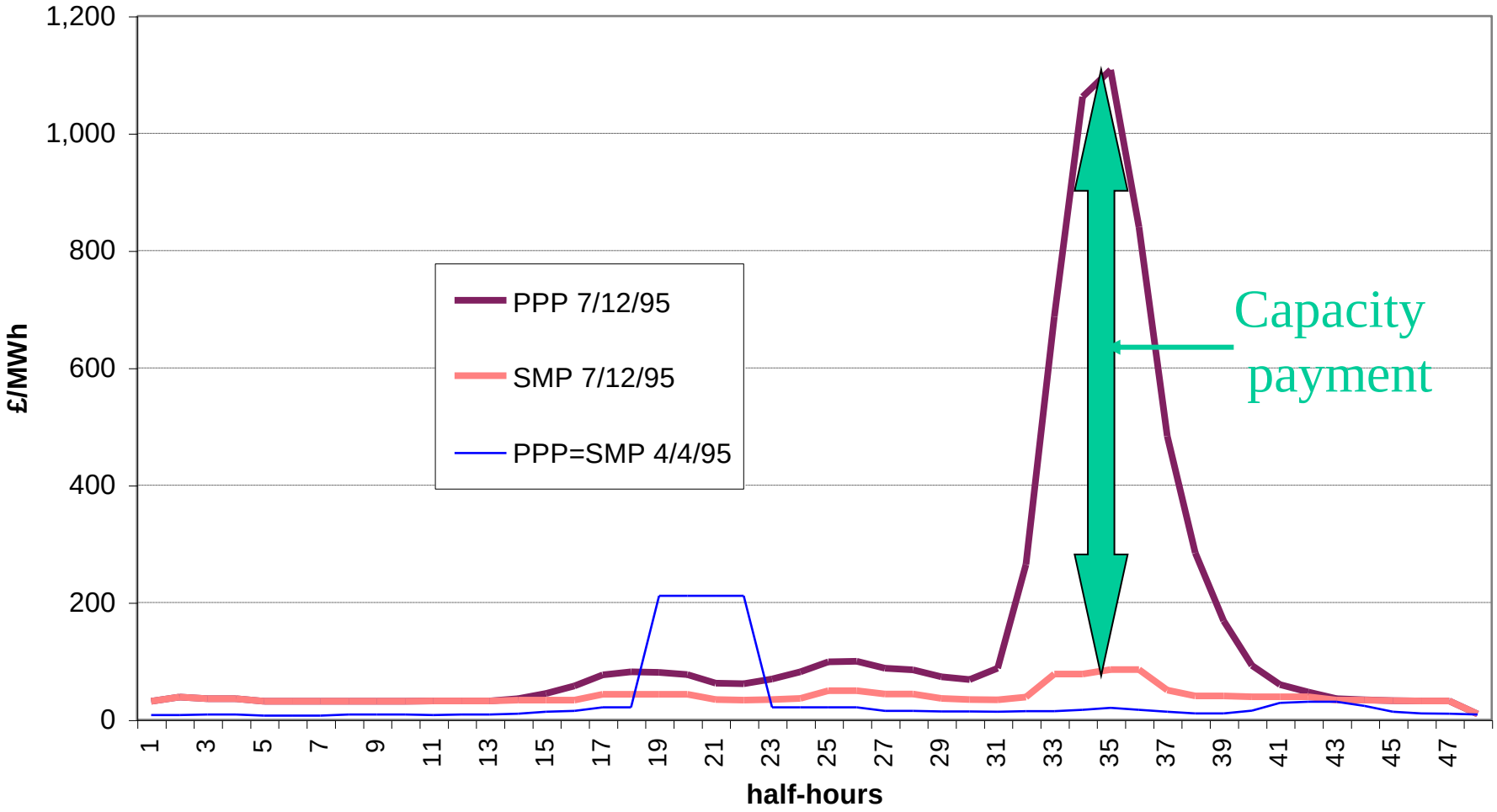
PowerGen Bid Prices 3 October 1990



Price duration curve UK RPD 2008



Electricity Pool Prices on two days in 1995



Supply functions in the Pool

- Generator offers amounts at increasing prices
- Demand varies over 48 half-hour periods
- SO selects cheapest offers to meet demand
- Single price auction: SMP = price of most expensive genset required
- Capacity payment = VOLL x LOLP
  - VOLL = £2,500/MWh in 1990 (indexed)
  - LOLP is exponential function of reserve

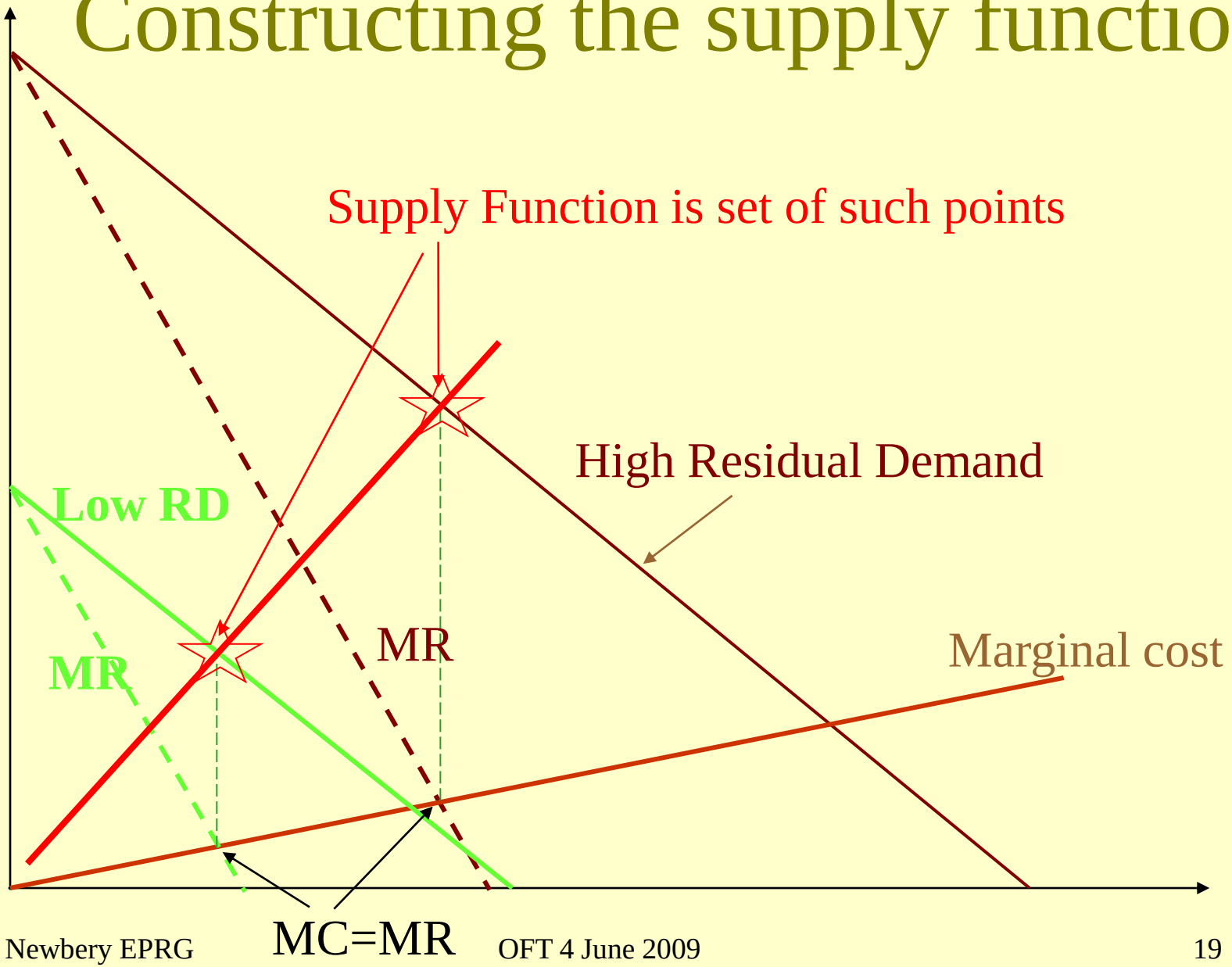
Equilibrium in Pool

- PPP = SMP + cap payment + ancillary services
- Generators optimise against residual demand
  - = demand *less* supply of all other generators
  - – for ***all*** demand realisations

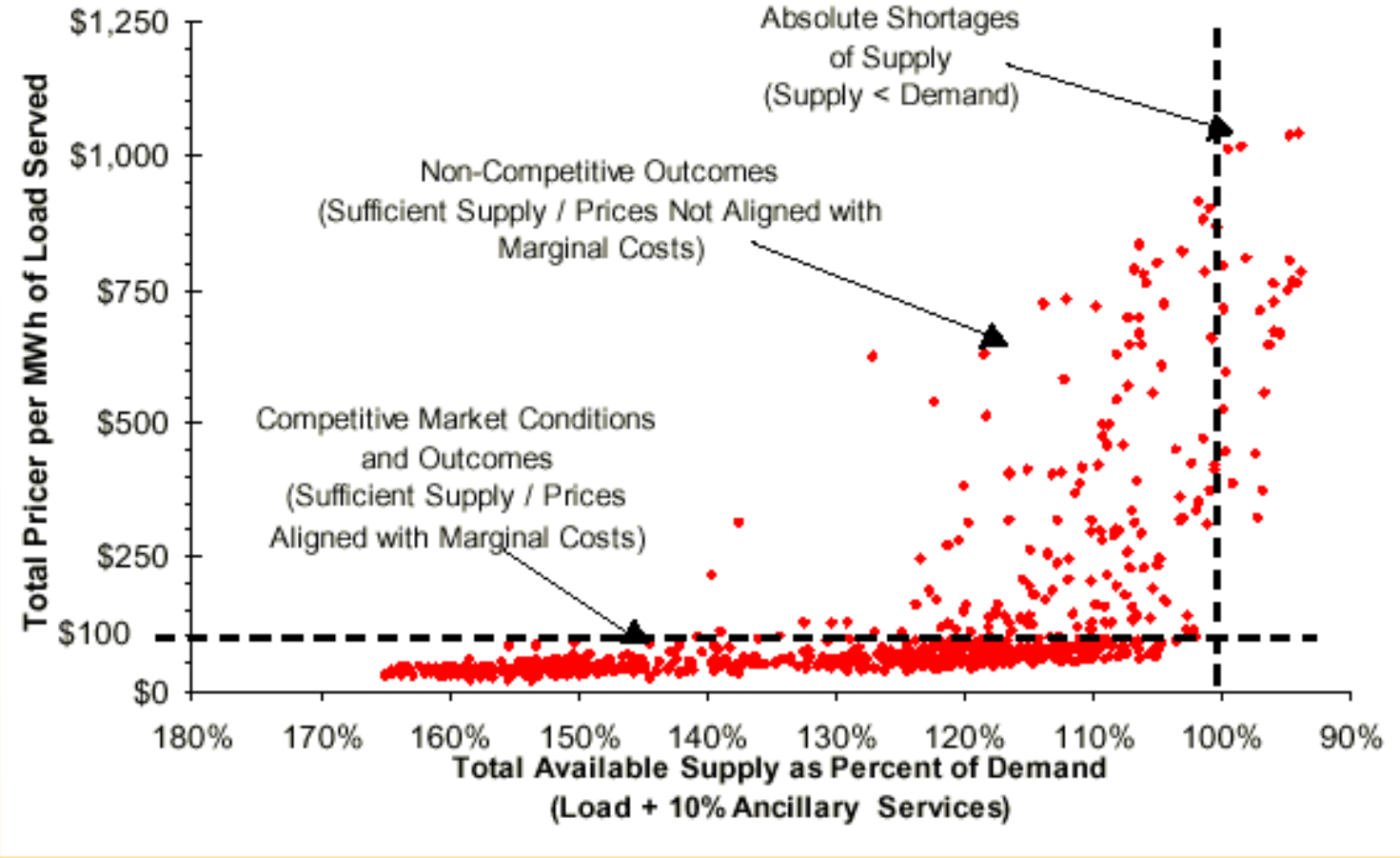
=> supply function for ***any*** residual demand

- Supply Equilibrium Equilibrium: best SF given choices of others (Nash Equilibrium in SFs)

Constructing the supply function



Scarcity or Market Power?



* Source: *Report on California Energy Market Issues and Performance: May-June, 2000*, Prepared by the Department of Market Analysis, August 10, 2000

Electricity prices in Europe

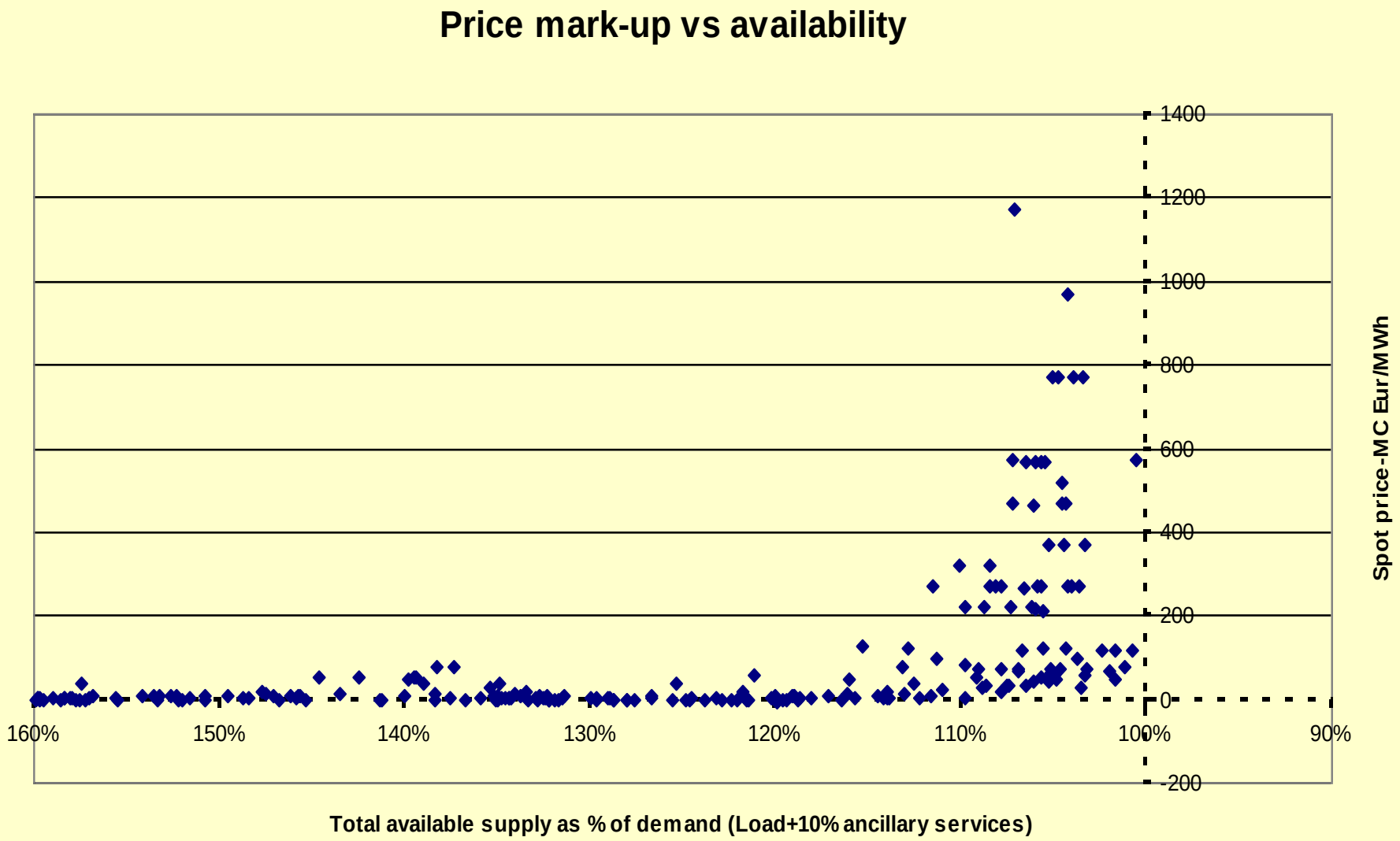
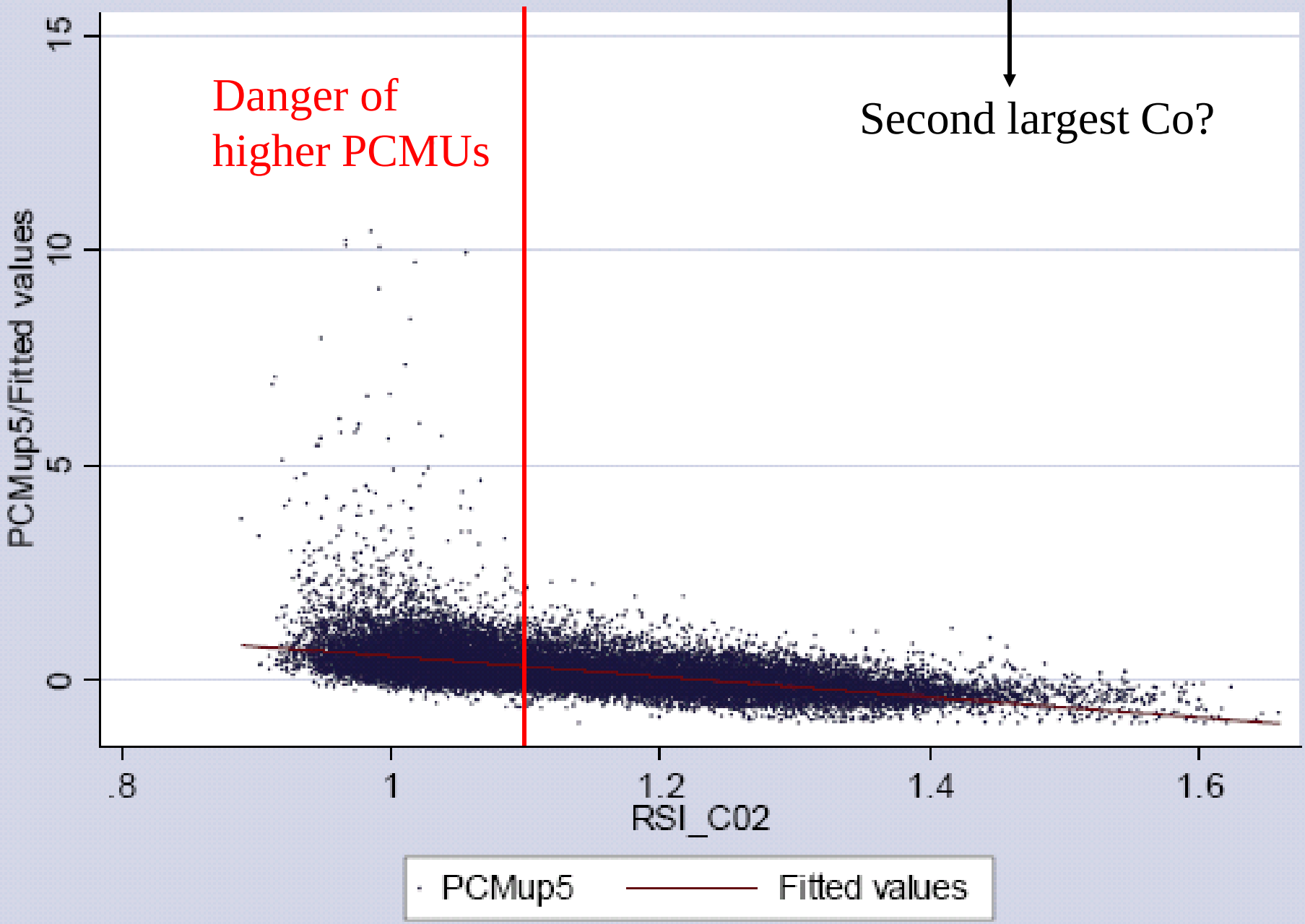


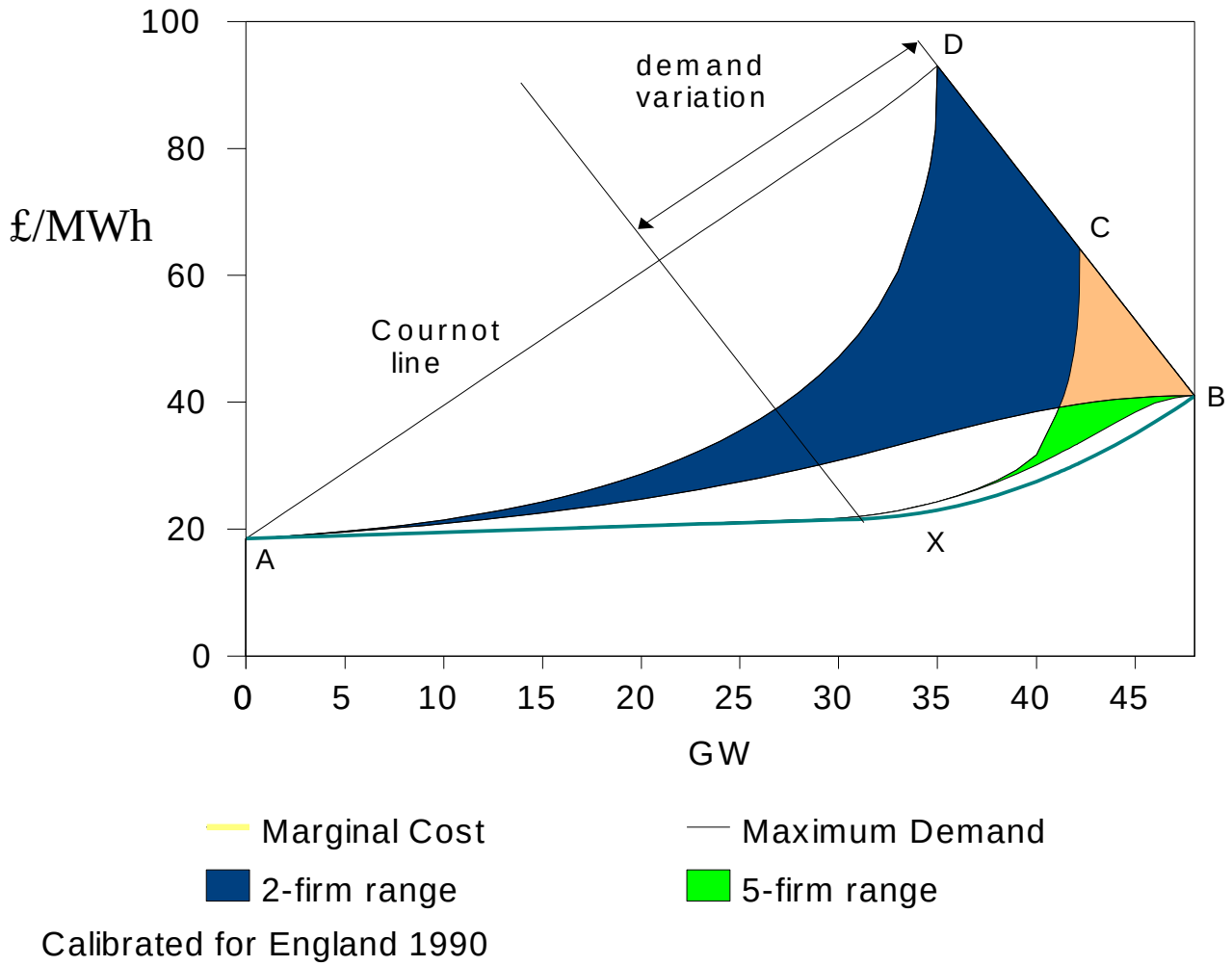
Figure 6.24: PCMU Regression on RSI 0436-S-DE



Modeling the Pool

- Green and Newbery (1992) argued that:
  - 2 firms setting price => high mark-ups
  - 5 equal sized firms => almost competitive
- Lost chance of restructuring at privatization
  - initial plan to include nuclear in "BigGen" (NP)
- First 10 years of Pool consequently fraught
  - induced entry, inquiries, divestiture but => NETA

Feasible Supply Functions
Duopoly and Quintopoly



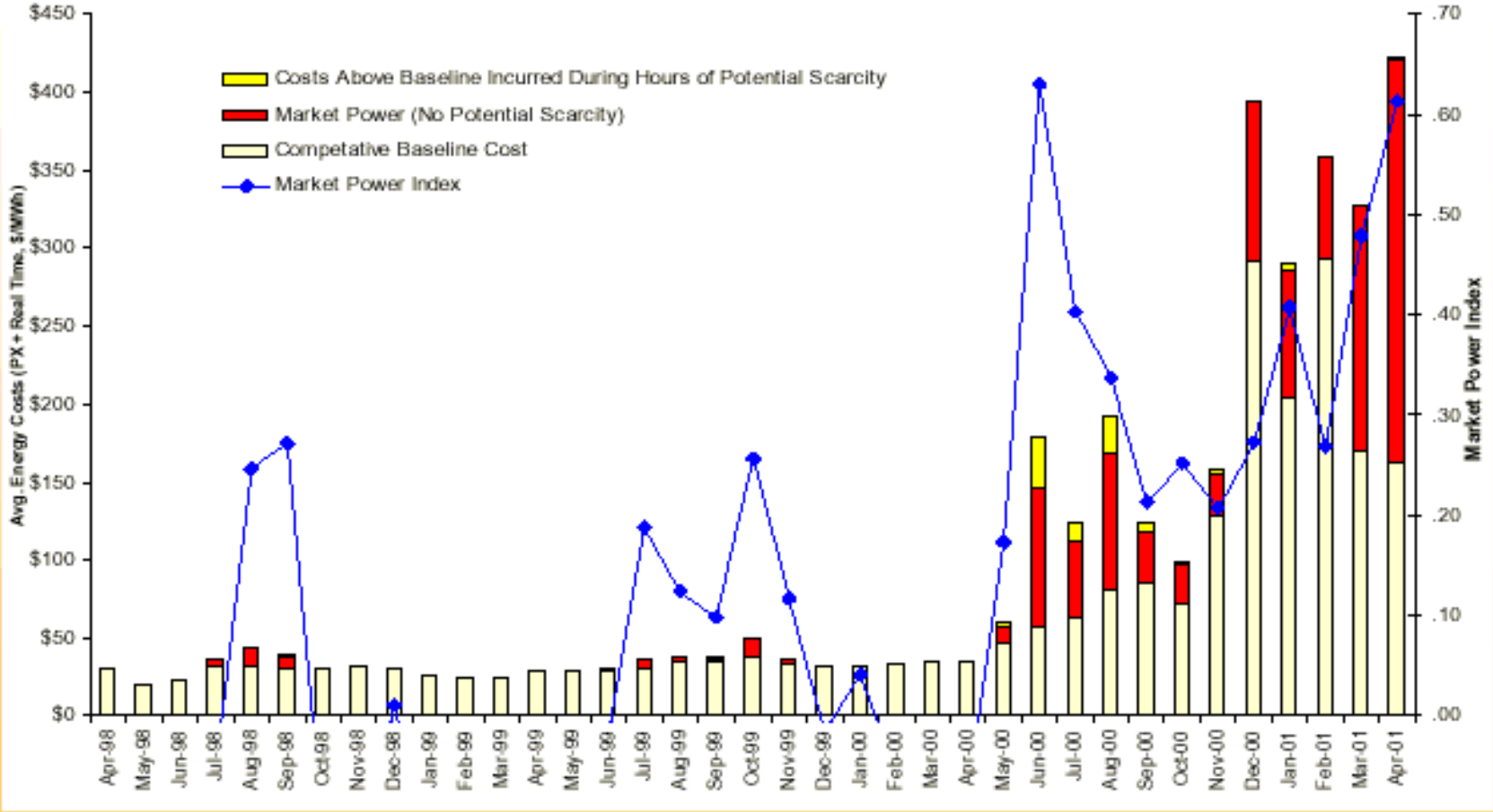
Calibrated for England 1990

Nature of SFE

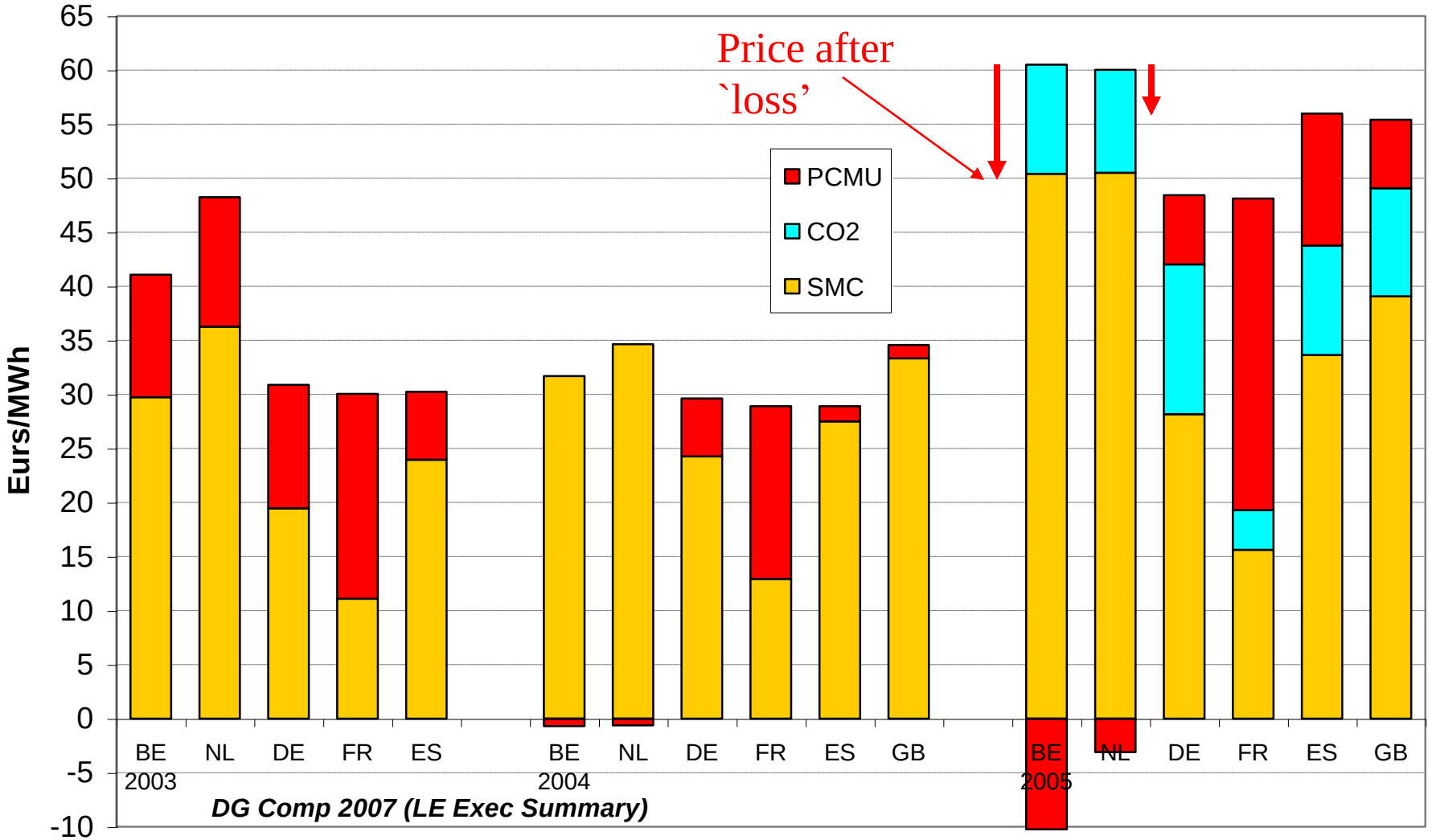
- Low levels of demand:
  - competition almost Bertrand, low mark-ups
- High levels of demand:
  - competition close to Nash-Cournot
- Appears to correspond to observation
- Lerner Index > 30%+? to recover fixed costs

What Explains the High Prices?

Prices above competitive levels were due to both higher production cost and higher mark-up from market power



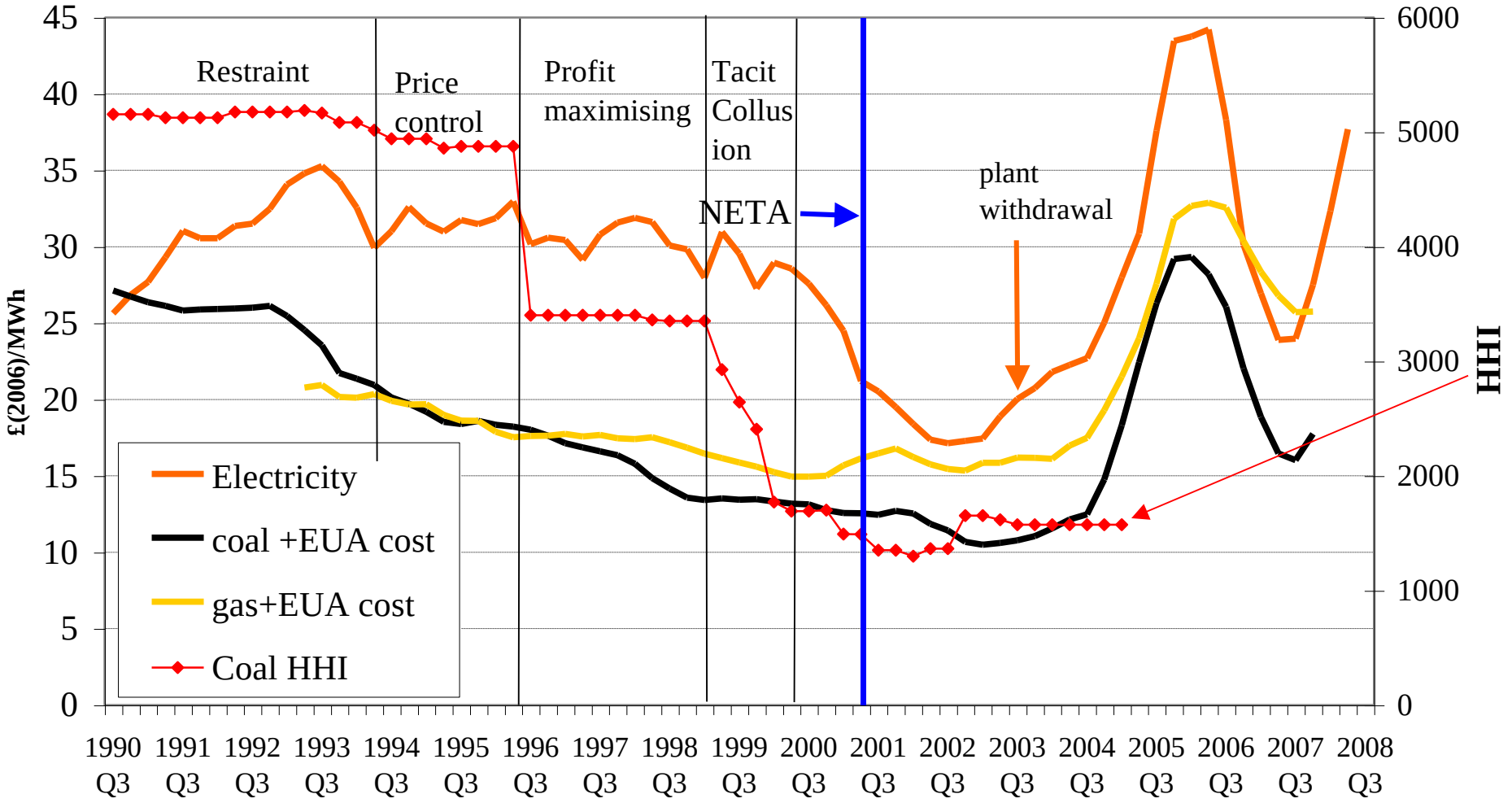
Price formation in 6 EU countries 2003-5



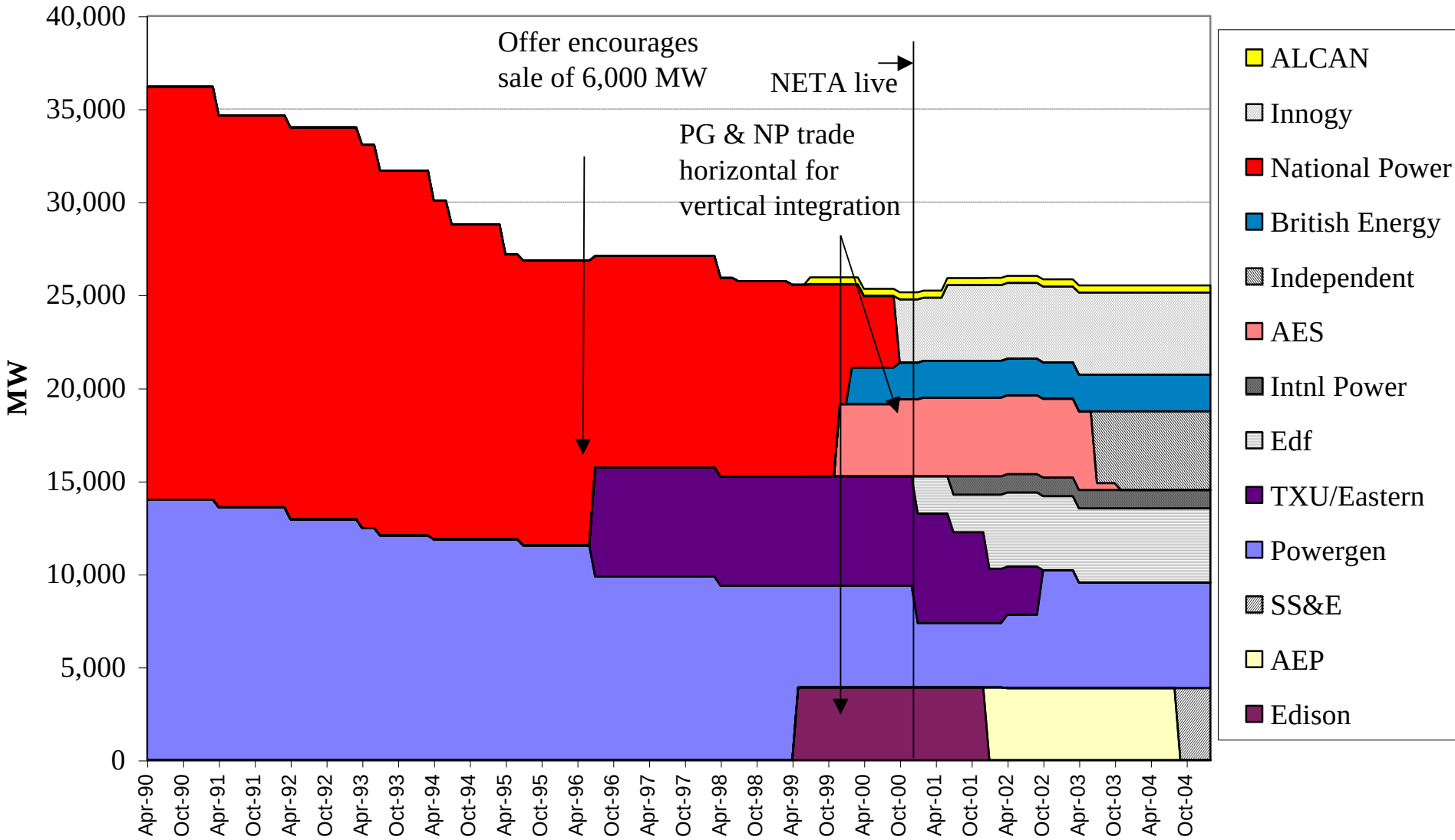
Testing for market power

- Andrew Sweeting (PhD MIT) obtains bids of all E&W gensets, demands, SMP for each half-hour
  - treat nuclear, CCGT etc as base-load
- estimates variable costs from fuel cost data
- determines residual demand facing each company
- is Co.'s supply function best response to RD?
- Finds three periods: restraint, profit maximising, collusion (less supply than individually rational)

Real GB electricity and fuel costs 1990-2007
centred annual moving averages



Capacity Ownership of Coal Generation 1990-2004



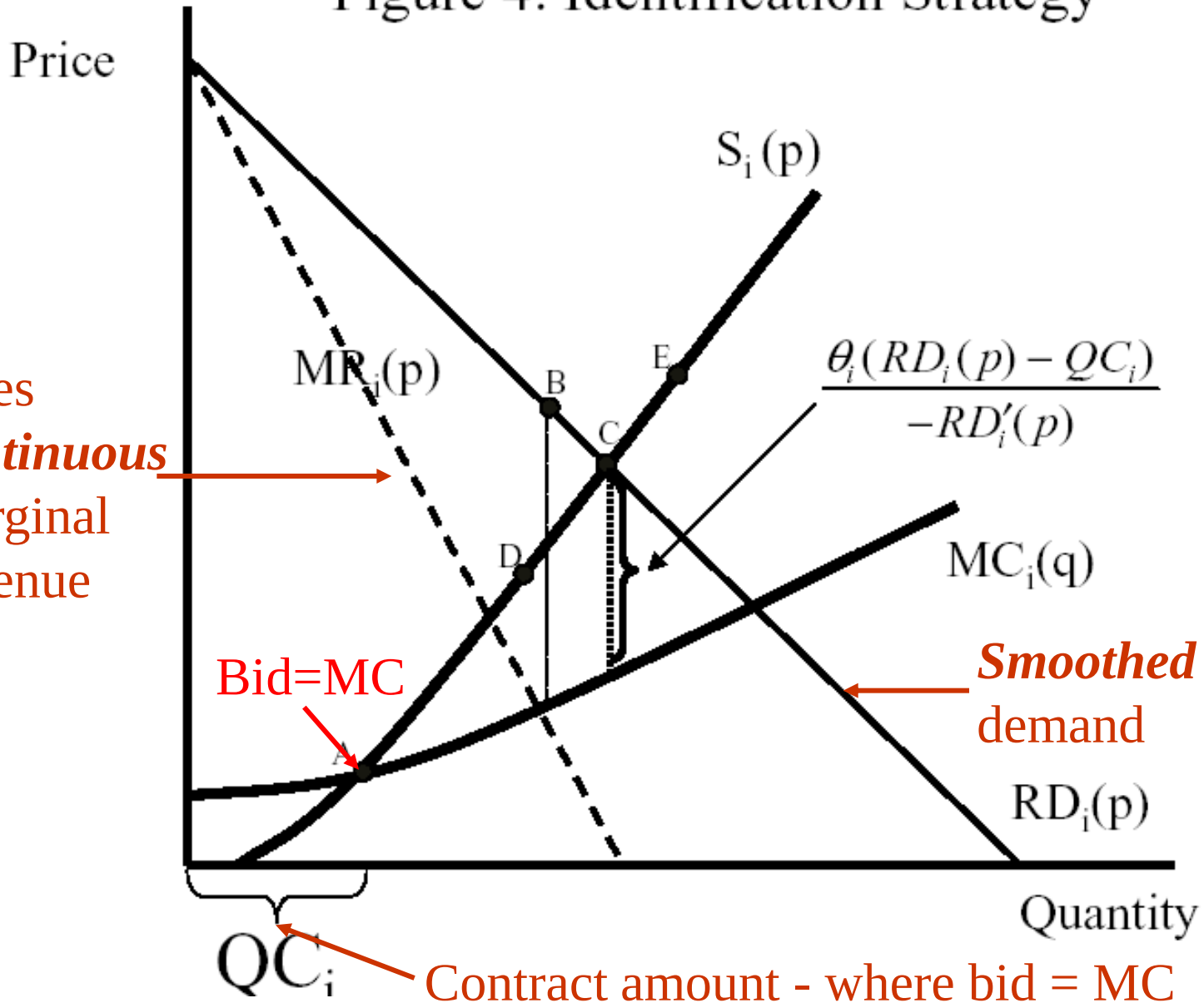
Source: NGC *Seven Year Statements*, various years, and data from J Bower and C Humphries, slide from D Newbery

The importance of contracts

- If contracts < supply to Pool sell surplus
  - would like a high price for surplus sales => p ⇑
- If contracts > supply to Pool buy shortfall
  - would like to buy cheaply => p ⇓
- Incentive to manipulate depends on ***net*** supply
- vesting contracts covered most output

  => mitigated potential market power

Figure 4: Identification Strategy



gives ***continuous*** marginal revenue

Bid=MC

Smoothed residual demand

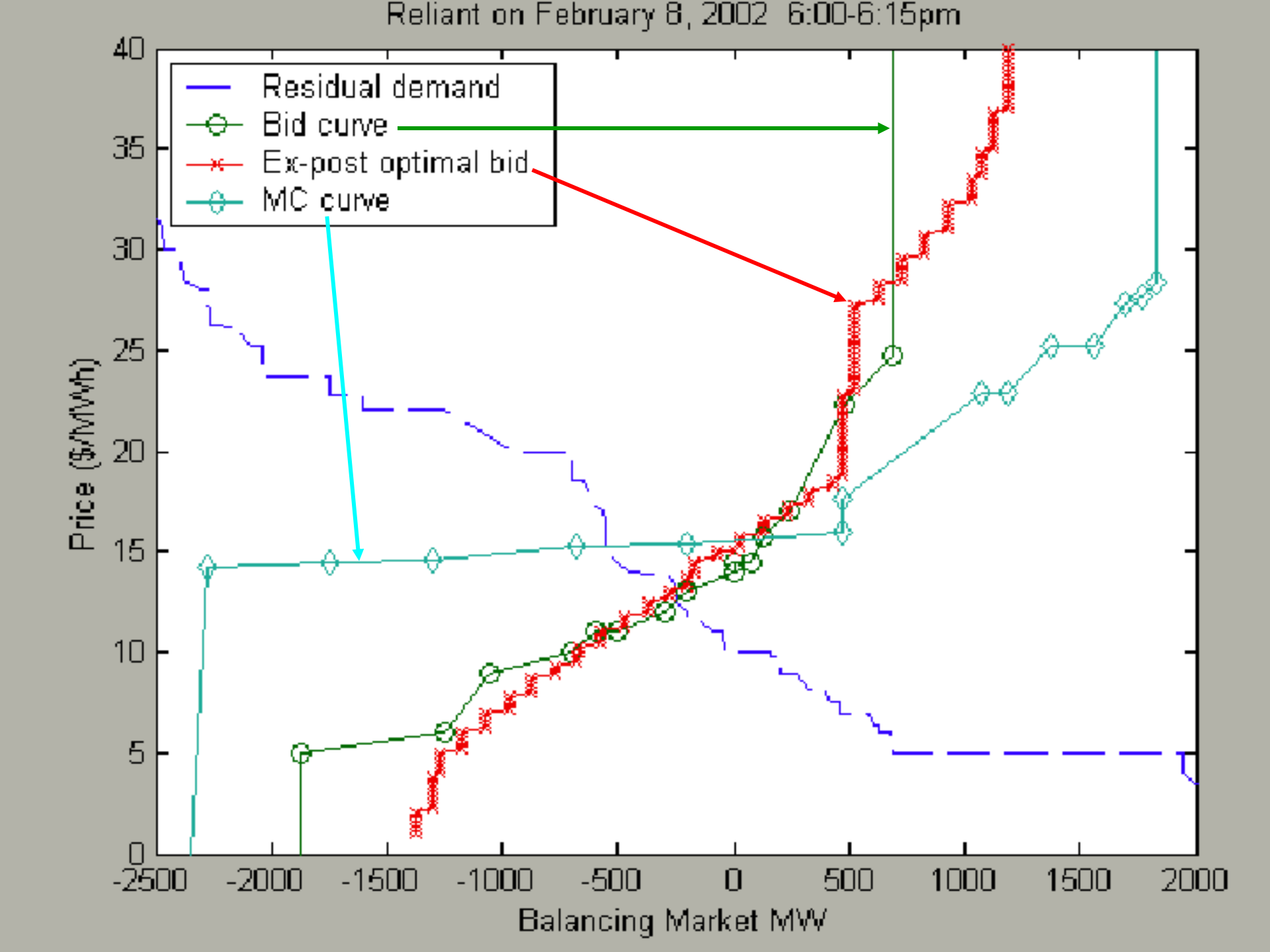
Contract amount - where bid = MC

Hortacsu-Puller model of ERCOT

- bids of all gencos available to regulator
- cost functions common knowledge => MC_i
- demand *less* other firms' bids = $RD_i(p)$
- can compute slope $RD_i'(p)$
- can compute $p - MC_i(S_i(p))$
- can compare this with actual bids
- can estimate θ (degree of market power) in

  $p - MC_i(S_i(p)) = \theta\{[S_i(p) - QC_i]/ RD_i'(p)\}$

  $\theta = 0$: competitive; $\theta = 1$: non-collusive optimum


Reliant on February 8, 2002 6:00-6:15pm
Residual demand
Bid curve
Ex-post optimal bid
MC curve
Price ($/MWh)
Balancing Market MW
40
35
30
25
20
15
10
5
0
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000

Objections to continuous SFE

- Power exchanges require stepped offers and bids (“price ladders”)

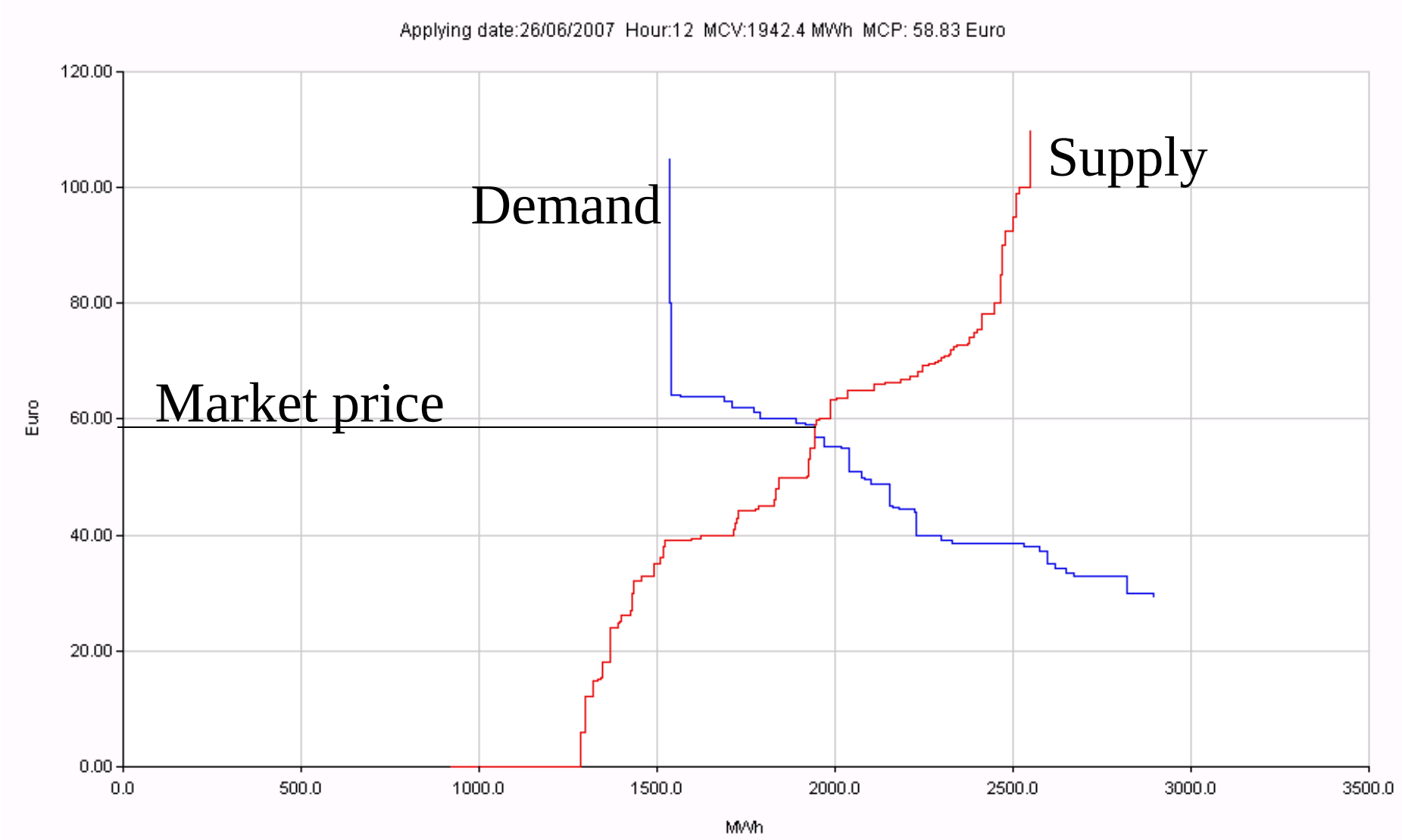
=> Residual demand stepped

=> poorly defined marginal revenue

=> multi-unit auctions

=> mixed strategies, unstable prices

Example from the Amsterdam Power Exchange



Holmberg, Newbery and Ralph (2008)

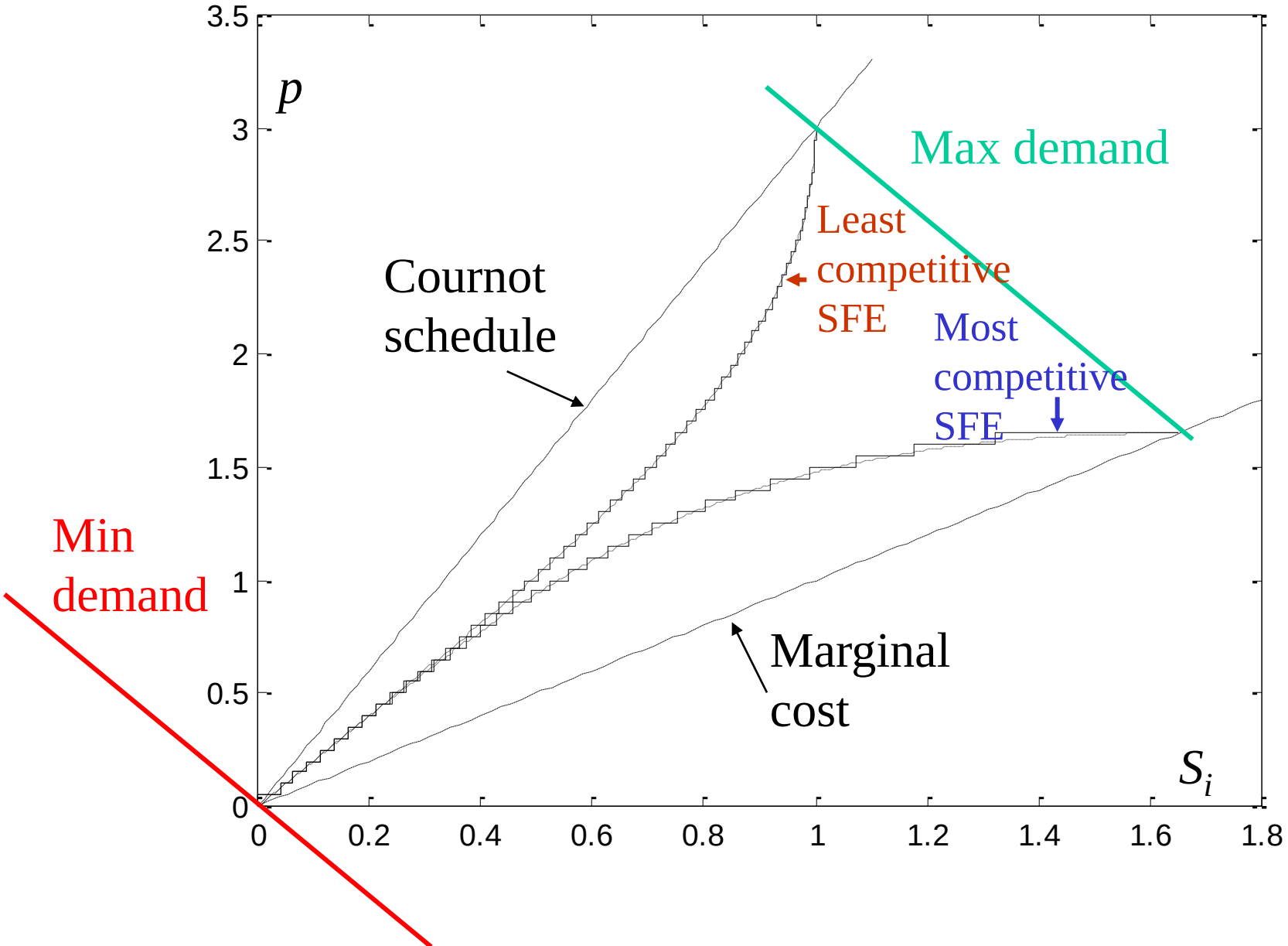
1. Stepped function SFE exist with discrete price grid
   - existence under the same conditions as continuous SFE

2. As number of price steps $M \to \infty$ the solutions to the stepped SFs converge to the continuous SFE

3. May be simpler to numerically compute step case

4. Justifies use of continuous SFEs

Example


p
S_i
Max demand
Least competitive SFE
Most competitive SFE
Cournot schedule
Marginal cost
Min demand
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

Conclusions

- Analysing electricity markets require new solution techniques: SFE fits data better
- Problems:
  - SFE depends on contracts
    - often unobserved,needed and obtained for *Sector Inquiry*
  - Multiple equilibria
    - reduced by contracts, capacity constraints
- Electricity markets can usefully be analysed using SFs - good data available

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