

Water and Power: Hydro Electric Resources in the Era of Competition

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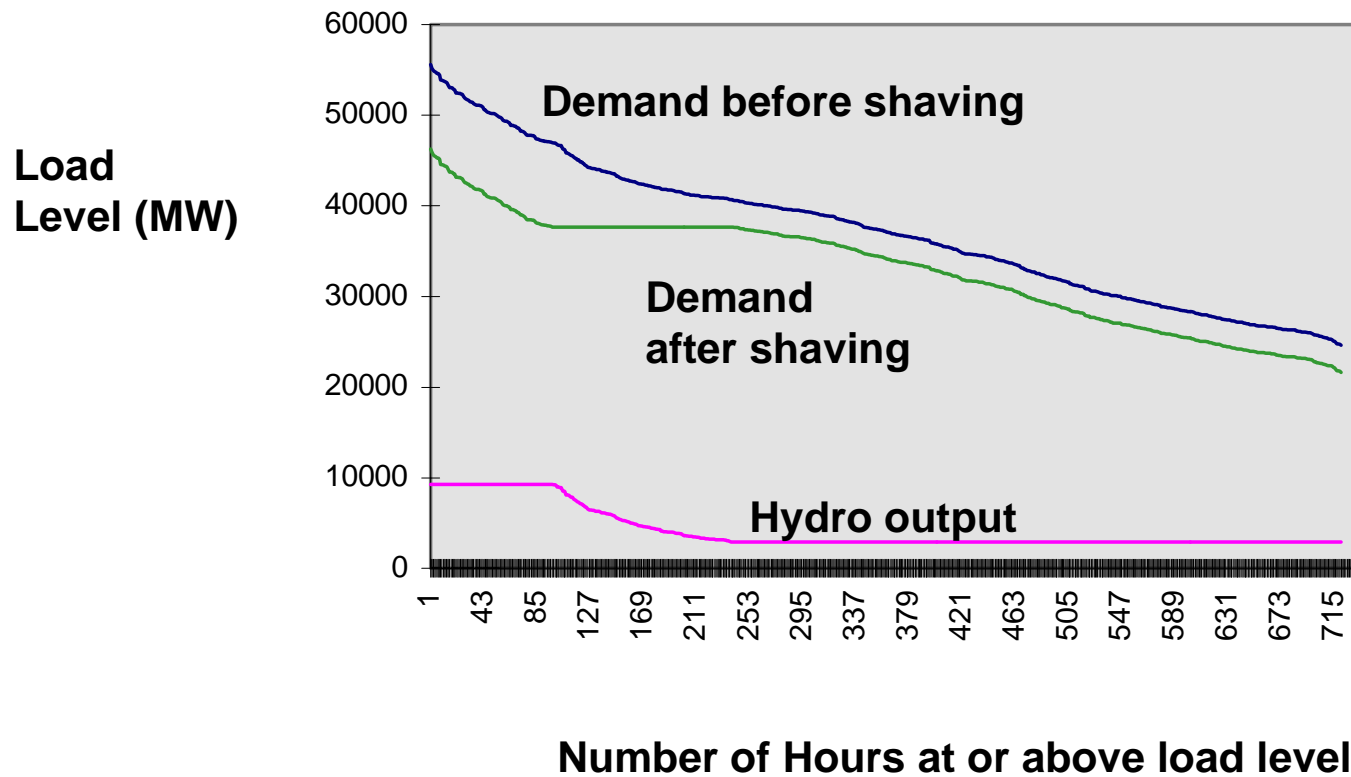
Outline

- **Misconceptions about hydro resources**
 - ‘cost’ of hydro energy
 - ‘advantages’ of hydro generation
- **‘Economic’ hydro scheduling**
 - Hydro scheduling and market power
 - Bifurcated Electricity Markets
- **Cournot framework for hydro competition**
- **California - Pacific northwest model of hydro-thermal competition**
 - market conditions

Economic Hydro Scheduling

- **Objective: to schedule a given amount of hydro energy to be released in a way that maximizes profits**
- **Simplifications**
 - No stochastic elements: thermal units ‘derated’ by FOR
 - No unit commitment costs
 - No production costs to hydro (besides opportunity costs)
 - ‘Short-run’ model: inflows do not effect the quantity of water released during the planning horizon
 - Empirical model assumes linear demand and linear marginal thermal costs

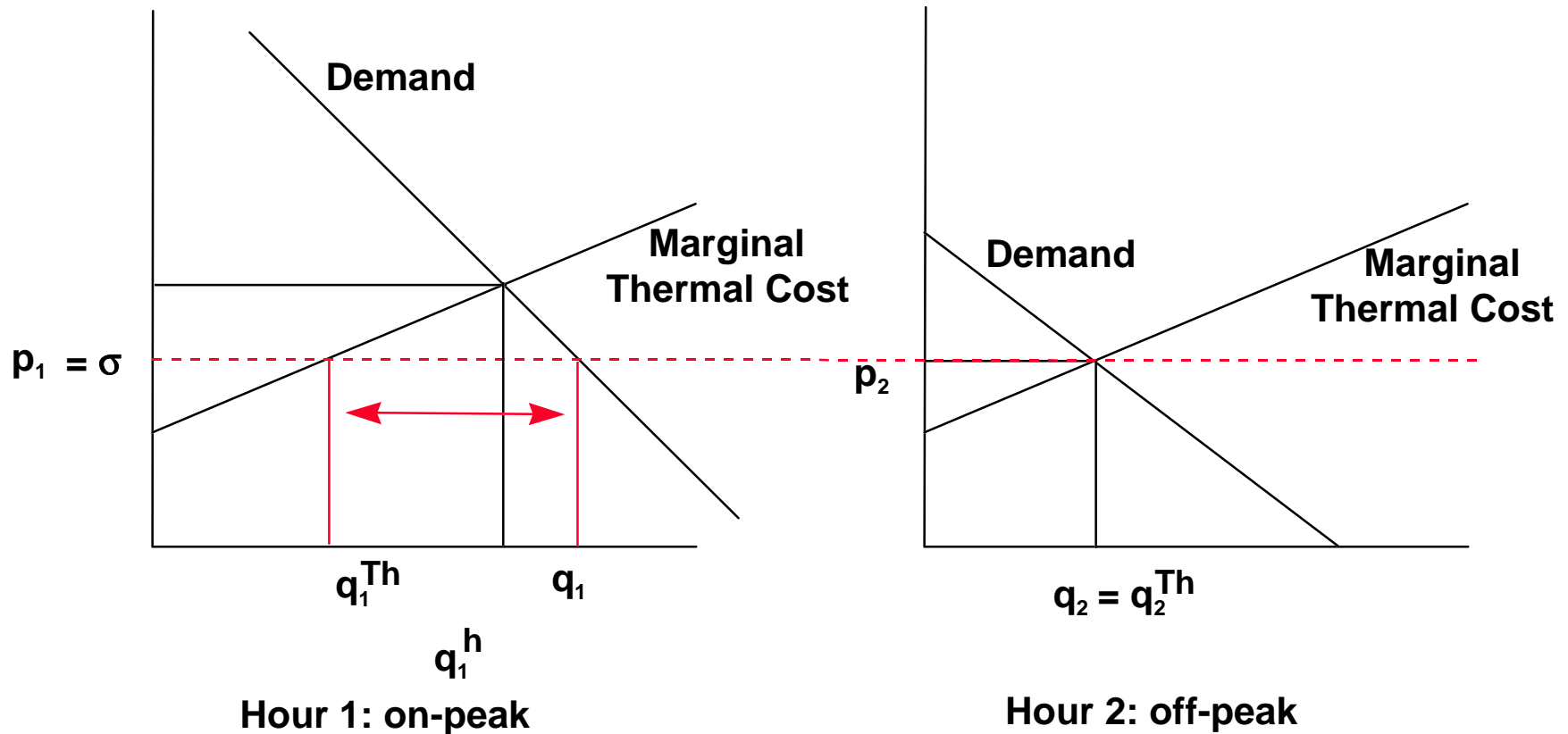
Peak Shaving With Hydro (inelastic demand)



Price Shaving with Hydro

'Dry' period: all water allocated to peak

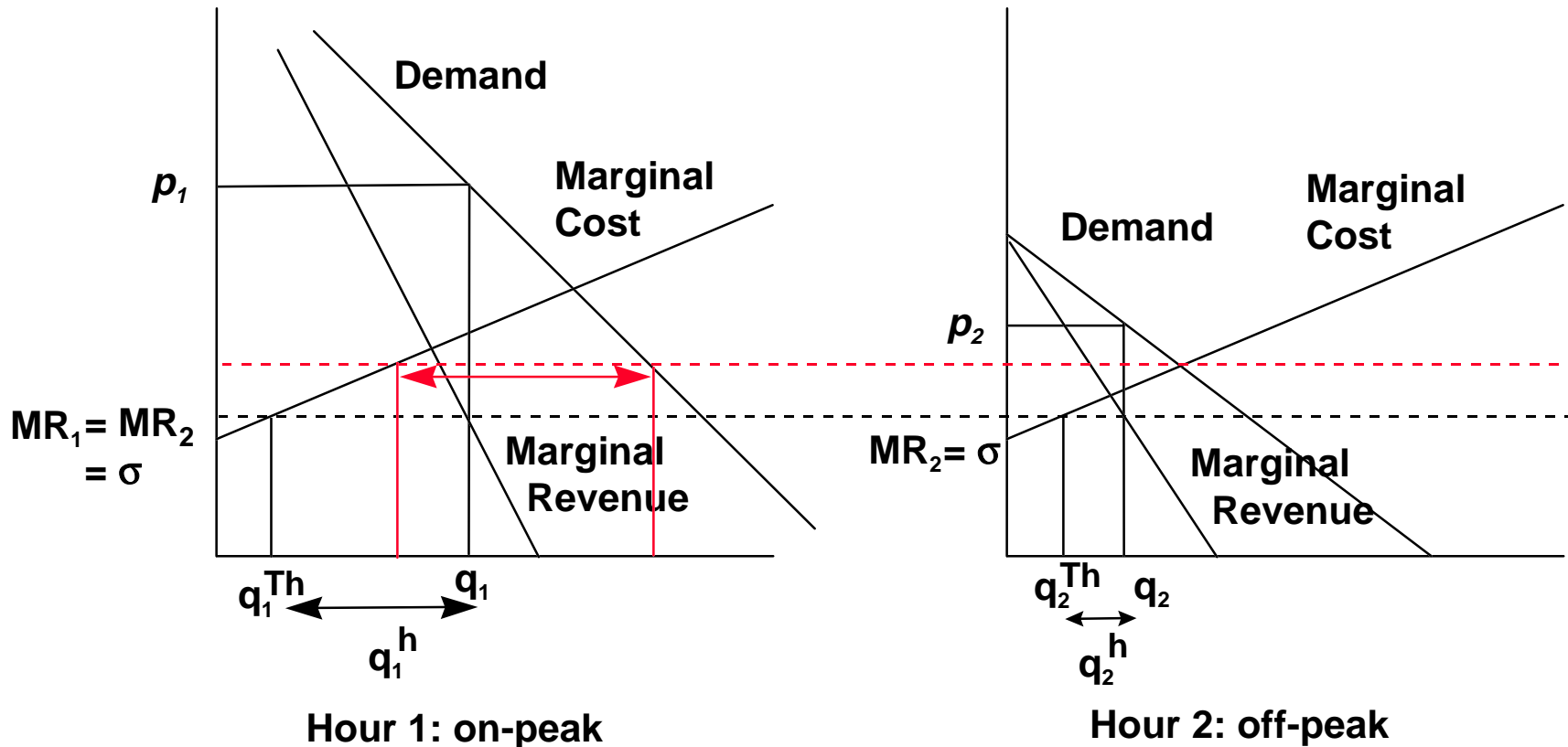
- Value of water σ equals price



Hydro and Market Power

'Dry' period: but water allocated to both hours

- Shave marginal revenue instead of price



The Bifurcation of Electricity Markets

- **Market power exercised in high demand periods, but not in low demand periods**
 - limits on fringe generation capacity
 - limits on transmission capacity
 - Electricity is expensive to store
- **Hydro power is the exception to the rule that electricity cannot be stored**
 - Competitive hydro firms can eliminate the separation between peak and off-peak markets
 - Strategic hydro firms can exacerbate this separation

Multiperiod Cournot Framework

- Each firm sets individual period outputs to maximizes total profits over all periods in the time horizon
- Maximization treats the vector of outputs of other hydro firms as constant (Cournot)
- Hydro outputs are constrained by
 - minimum flow limit - with shadow price δ
 - maximum flow limit - with shadow price γ
 - total hydro output during the time horizon has to equal the water available for output - with shadow price σ

Equilibrium Conditions

- For each Cournot firm i

$$p_t + \frac{\partial p_t}{\partial Q_t} q_{it} = \sigma_i + \gamma_{it} + \delta_{it} = c_i(q_{it}^{Th})$$

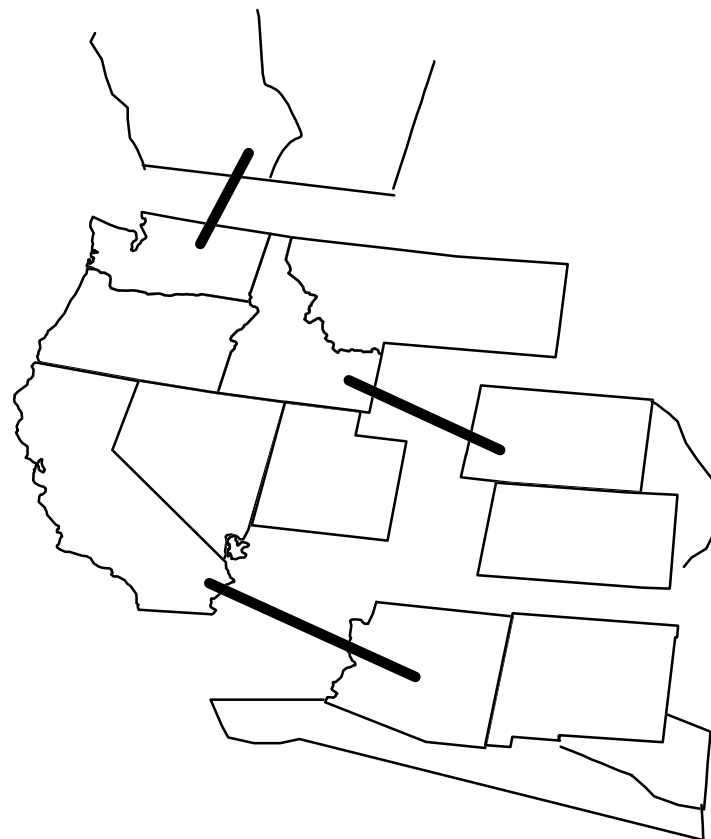
Marginal Revenue = Marginal Cost

- Fringe hydro production

$$p_t = \sigma_f + \gamma_{ft} + \delta_{ft}$$

California-northwest (CNW) regional market

- **California & Pacific northwest combined into one regional market**
- **Excess capacity from Canada, Rocky Mountains, and the southwest assumed to be exported into CNW**
- **PG&E, SC&E, and BPA considered to be Cournot players**
- **All other firms assumed to be price-taking fringe**



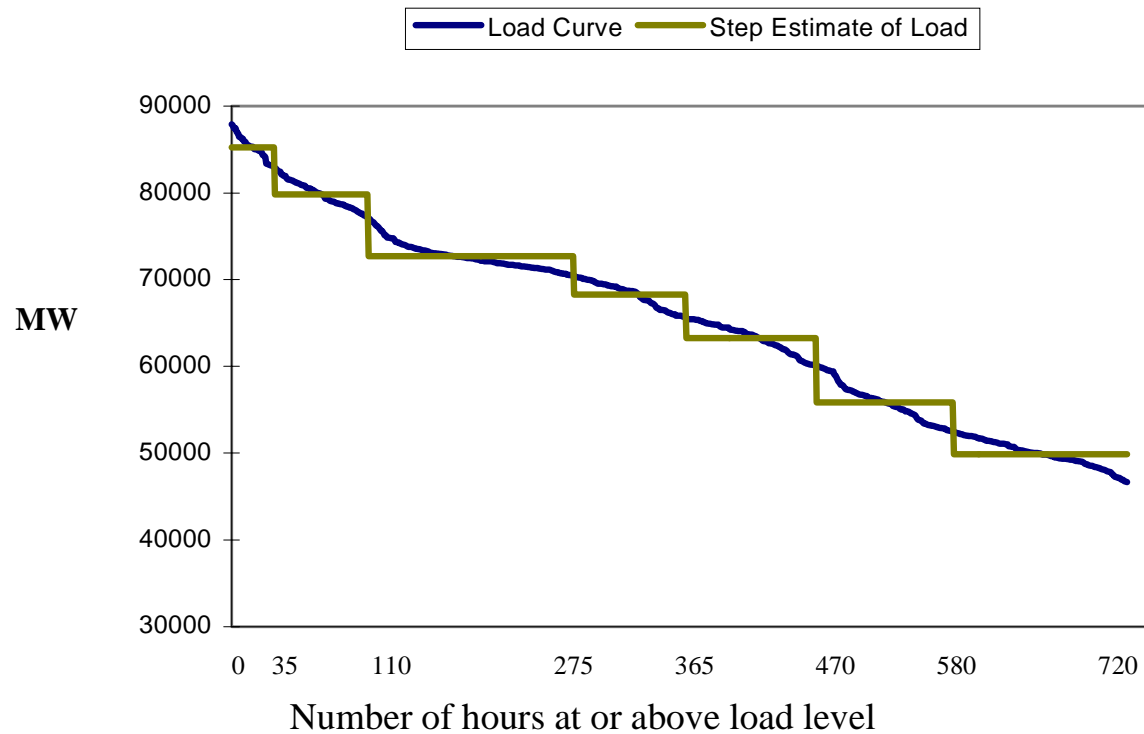
California-northwest Supply resources and 2001 peak demands

	PG&E	SCE	BPA	Fringe
Pondage Hydro	2676	932	20212	19240
Pumped Hydro	1056	206	0	3612
Thermal	6182	10331	1054	37154
Total Capacity	9914	11469	21266	60006
% of CNW Capacity	10%	11%	21%	58%
% of CNW Energy (September 1995)	14%	16%	16%	53%
% of CNW Energy (March 1995)	14%	11%	22%	52%
	March	June	Sept	
CNW peak demand	73,292	79,147	85,238	

Modeling Assumptions of Basecase (continued)

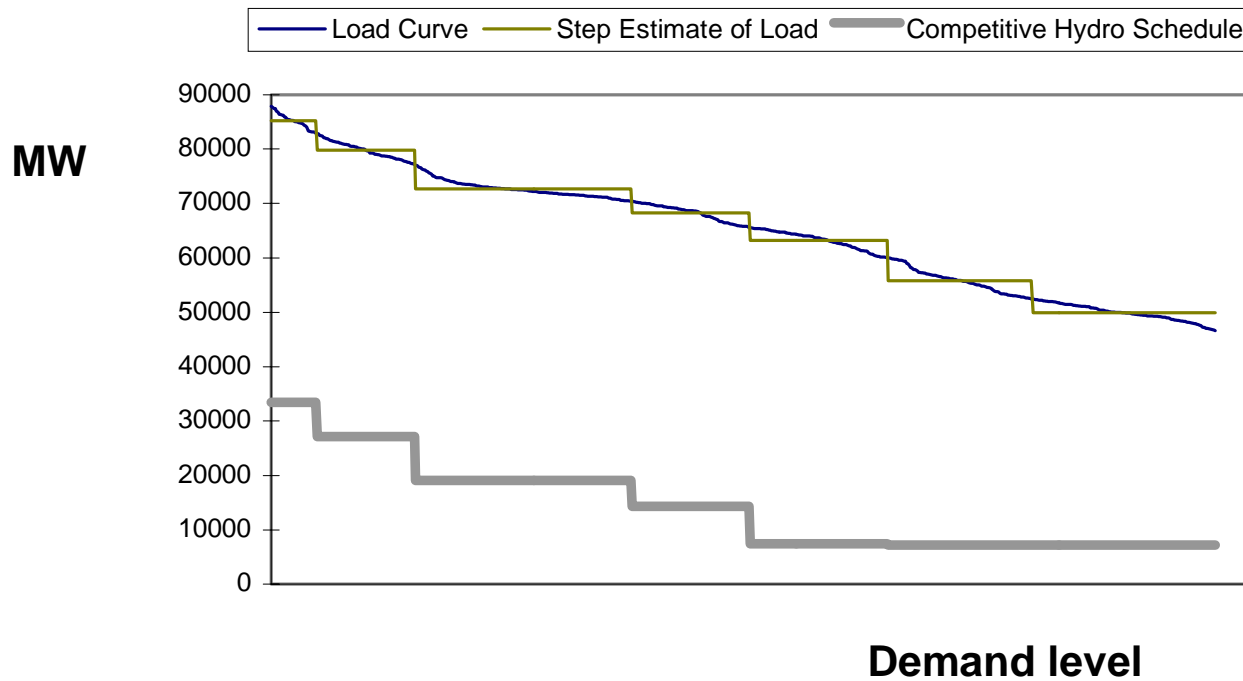
- **Demand - $q = a - bp$**
 - a, b set such that demand passes through year 2001 forecast demand levels at their forecast price of 7.7 cents/KWh with an elasticity of 0.1 at that point.
 - Estimate local T & D costs at 3.5 cents/KWh
- **No transmission losses or congestion within CNW region**
- **Thermal units derated by their forced outage rates**
- **“Special” units**
 - California Nuclear assumed to be must-run
 - All IPP capacity assumed available and must-run

Step-wise approximation to monthly load duration curve

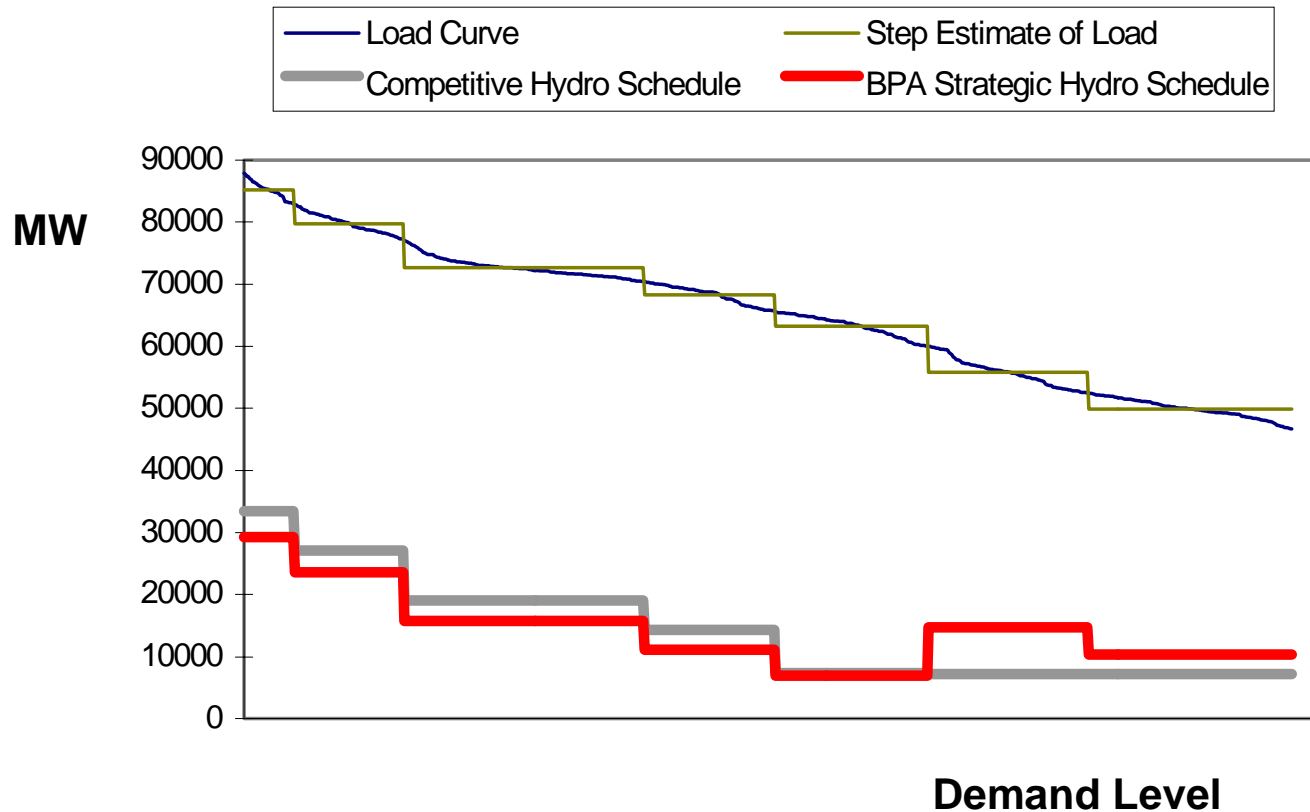


September Hydro Schedule: All Firms Price-Shaving

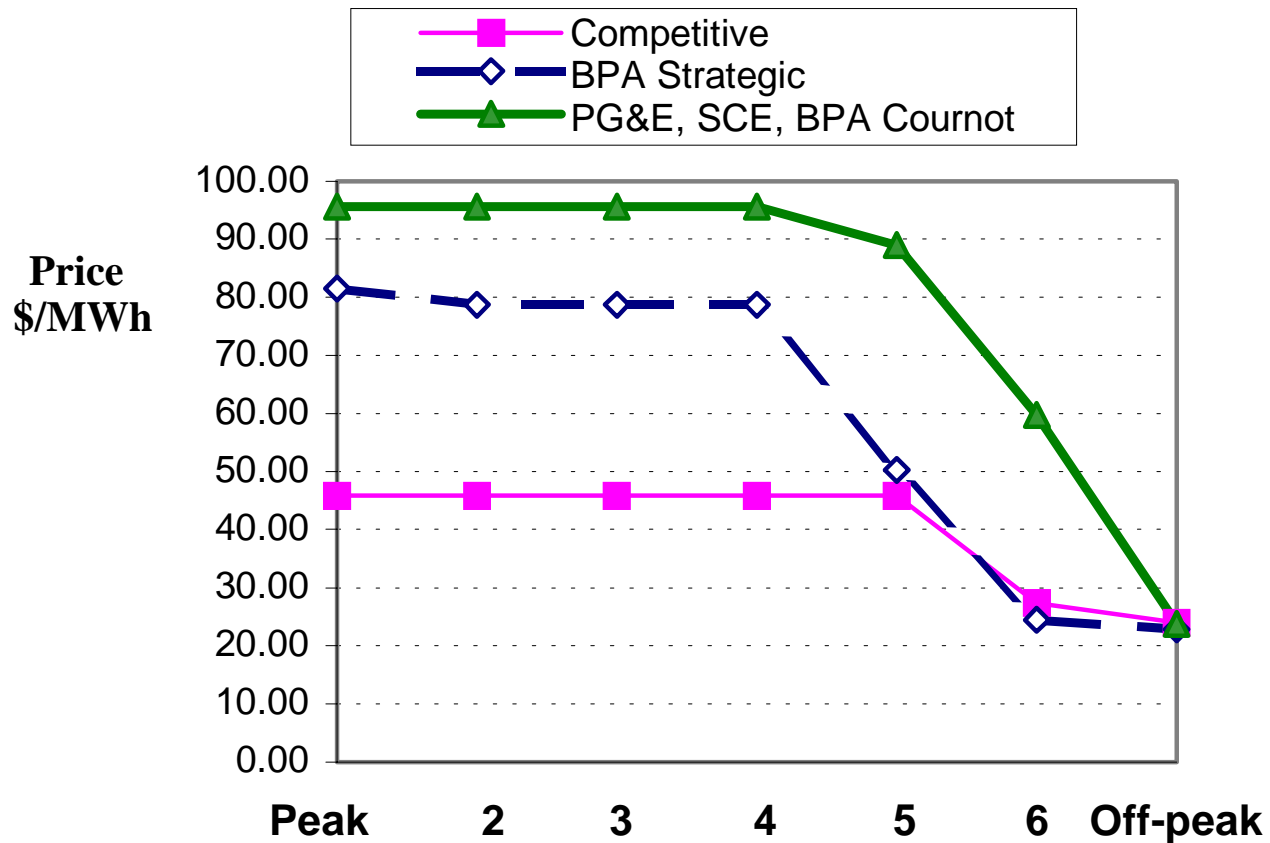
September Total CNW Hydro Output



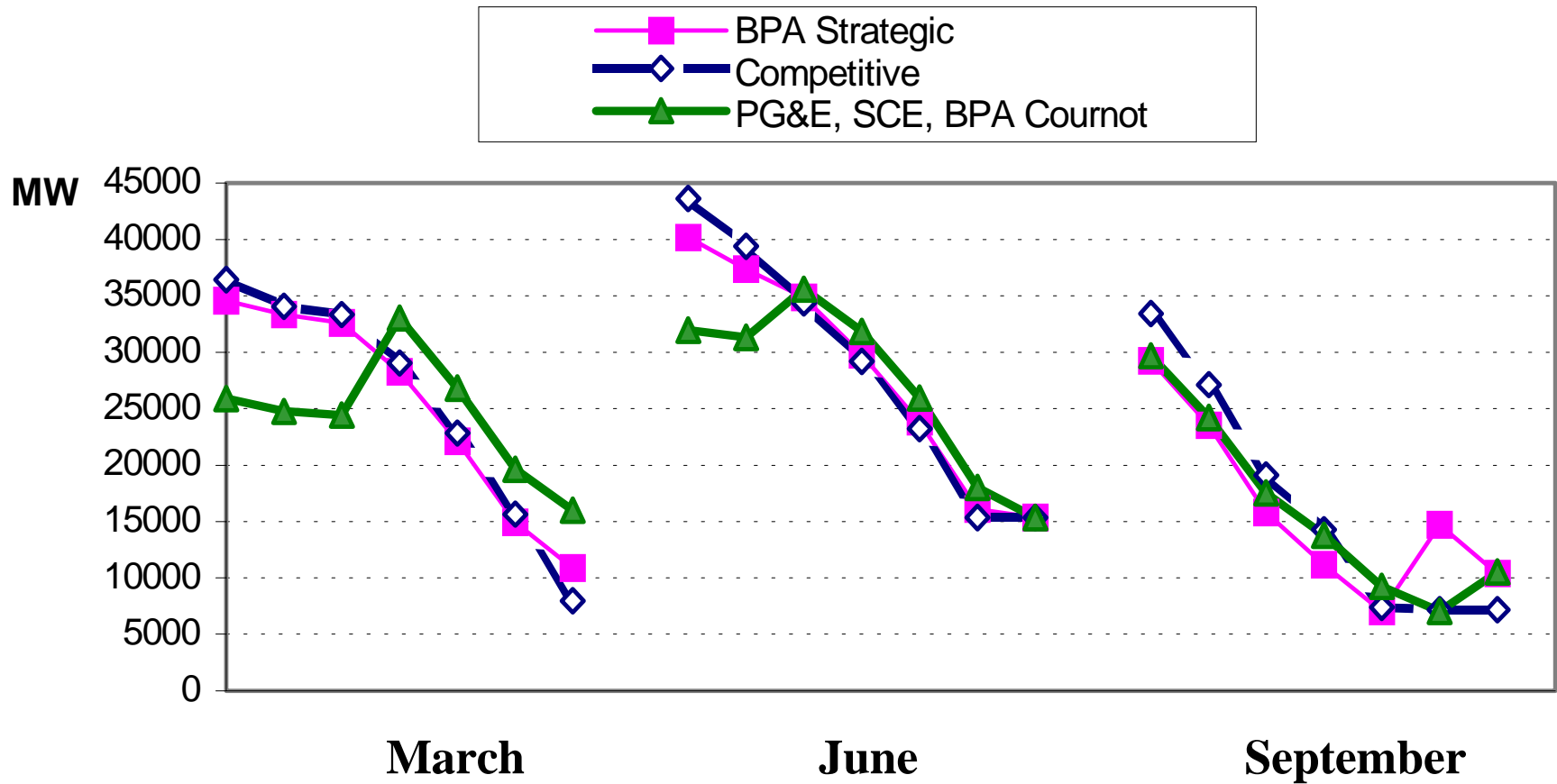
September Hydro Schedule: BPA Shaving Marginal Revenue



September Equilibrium Prices

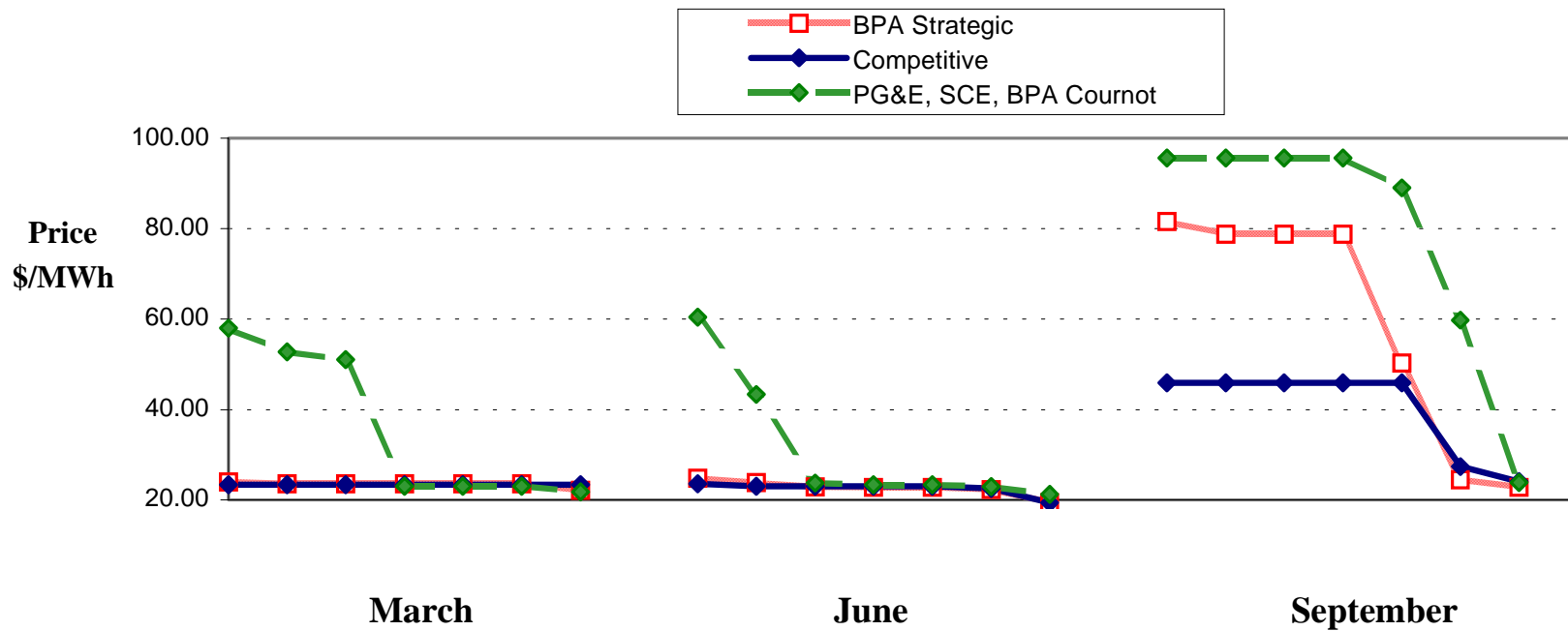


Equilibrium CNW Hydro Output

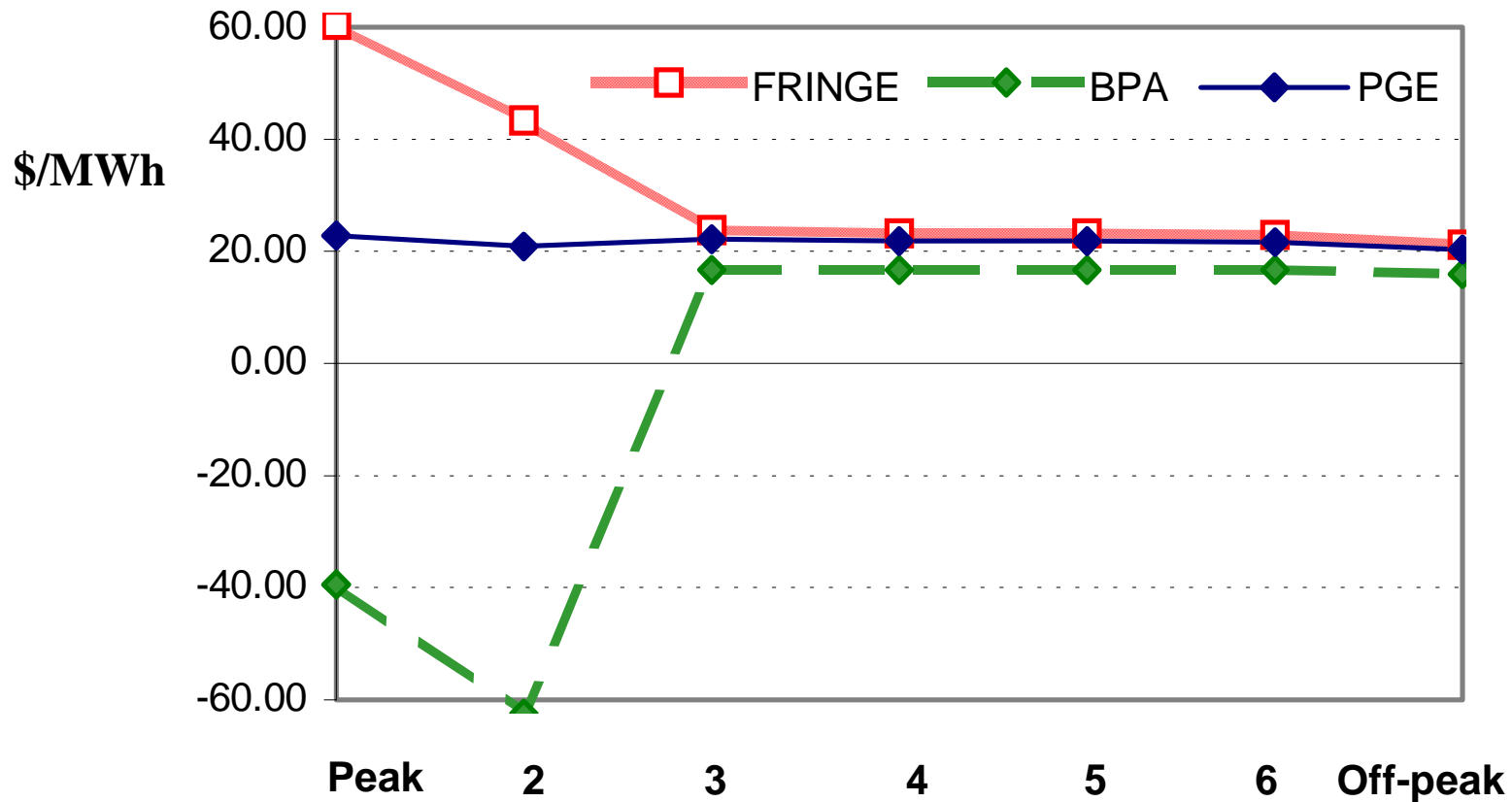


Equilibrium Prices

CNW Equilibrium Prices by Demand Level



Shadow Prices on Flow Constraints: June Hour by Hour Water Values



Summary

- **Strategic hydro firms will ‘shave’ marginal revenues rather than prices**
 - This can distort hydro production from its most efficient usage
 - The severity of these distortions will depend upon the characteristics of the hydro systems
- **‘Pivotal’ hydro firms can find it profitable to shift production from peak to off-peak periods**
 - In the context of the CNW market, BPA appears to be such a firm.