

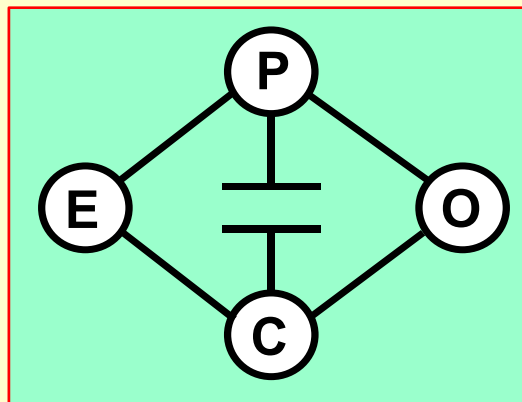
Models for Optimizing in Electricity Markets

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Summary

- Why participant behaviour matters
- Market simulators
- Stochastic programming
- Equilibrium Models
- Simulation/Optimization Models
- Optimization for the Electricity Commission
- Conclusions

A thought experiment...

- Suppose the EC offers power at 12c/KWHr
- This caps the price and hence future water value
- Hydro generators offer at 11.999c/KWHr
 - undercutting to capture more generation
- The EC is not dispatched until lakes hit bottom
- Prices are capped but are consistently high for many months
- EC loses money and must charge a high levy
- High cost of security of supply

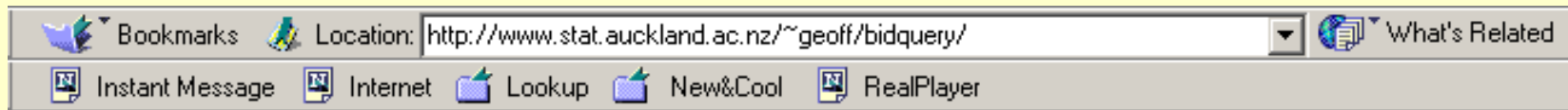
Why participant behaviour matters

- It seems plausible but will it happen?
- If it does then...
 - 1 in 60 may not be guaranteed
(how would we know?)
 - it may cost the industry a high levy
- The EC offering policies should try and account for responses of market participants

Market simulators

- Choose an operating policy for each generator over a planning horizon
- Construct inflow/energy demand scenarios over planning horizon
- Solve dispatch/pricing problem for each trading period within each scenario
- Extract probability distributions of prices and shortages.
- Simulator a key ingredient in evaluating a policy

BidQuery



NZ Electricity Market generators' offers

This site shows the electricity offered for sale by generators to NZEM in recent times. All the graphs and tables are produced by [BidQuery](#) from publicly available data provided by market operator [M-Co](#).

Whole-of-industry offers:

- [Last 3 months](#)
- [Last 12 months](#)

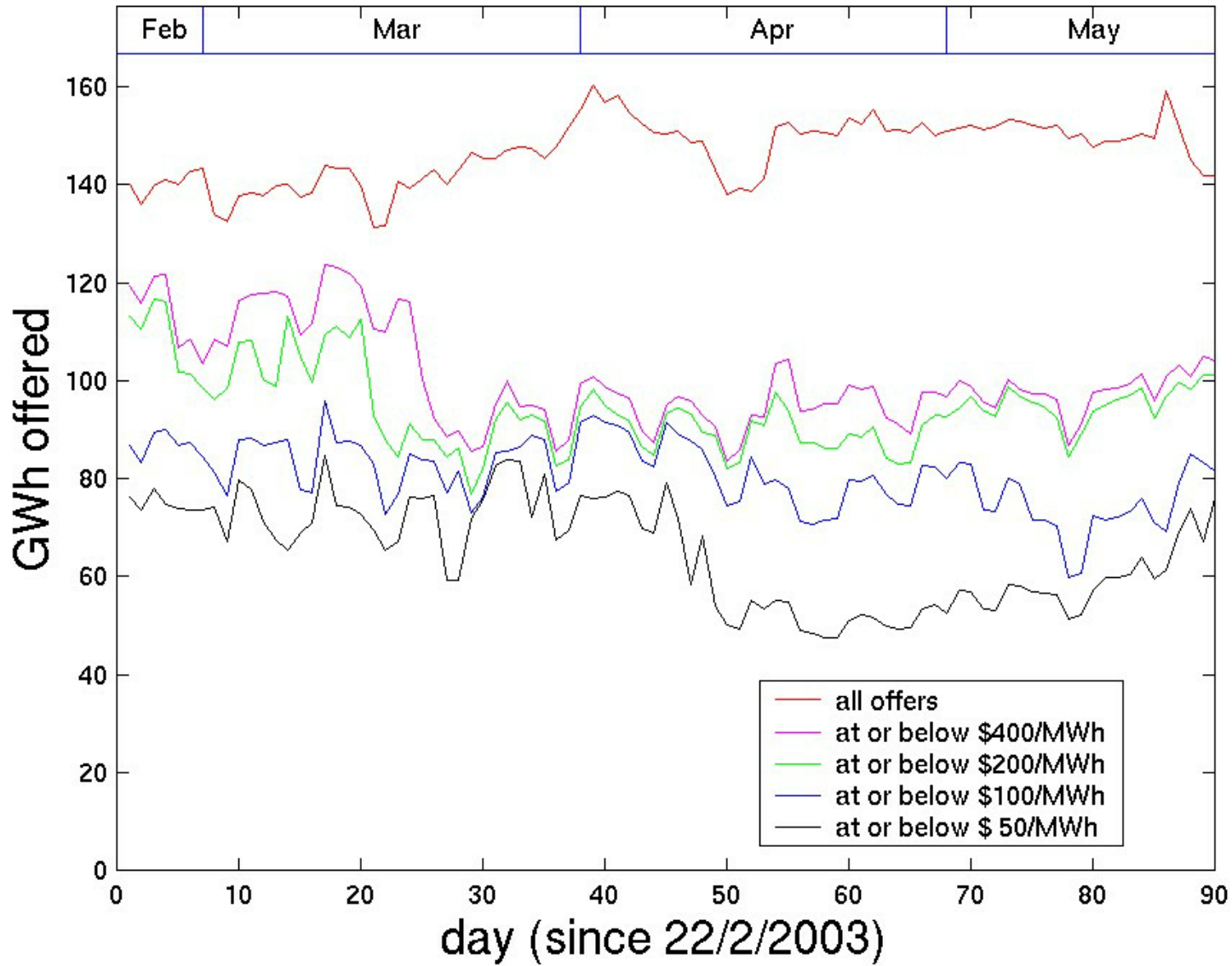
Offers by the main generation owners:

- [Mighty River Power](#)
- [Contact Energy](#)
- [Genesis](#)
- [Meridian](#)
- [Trustpower](#)

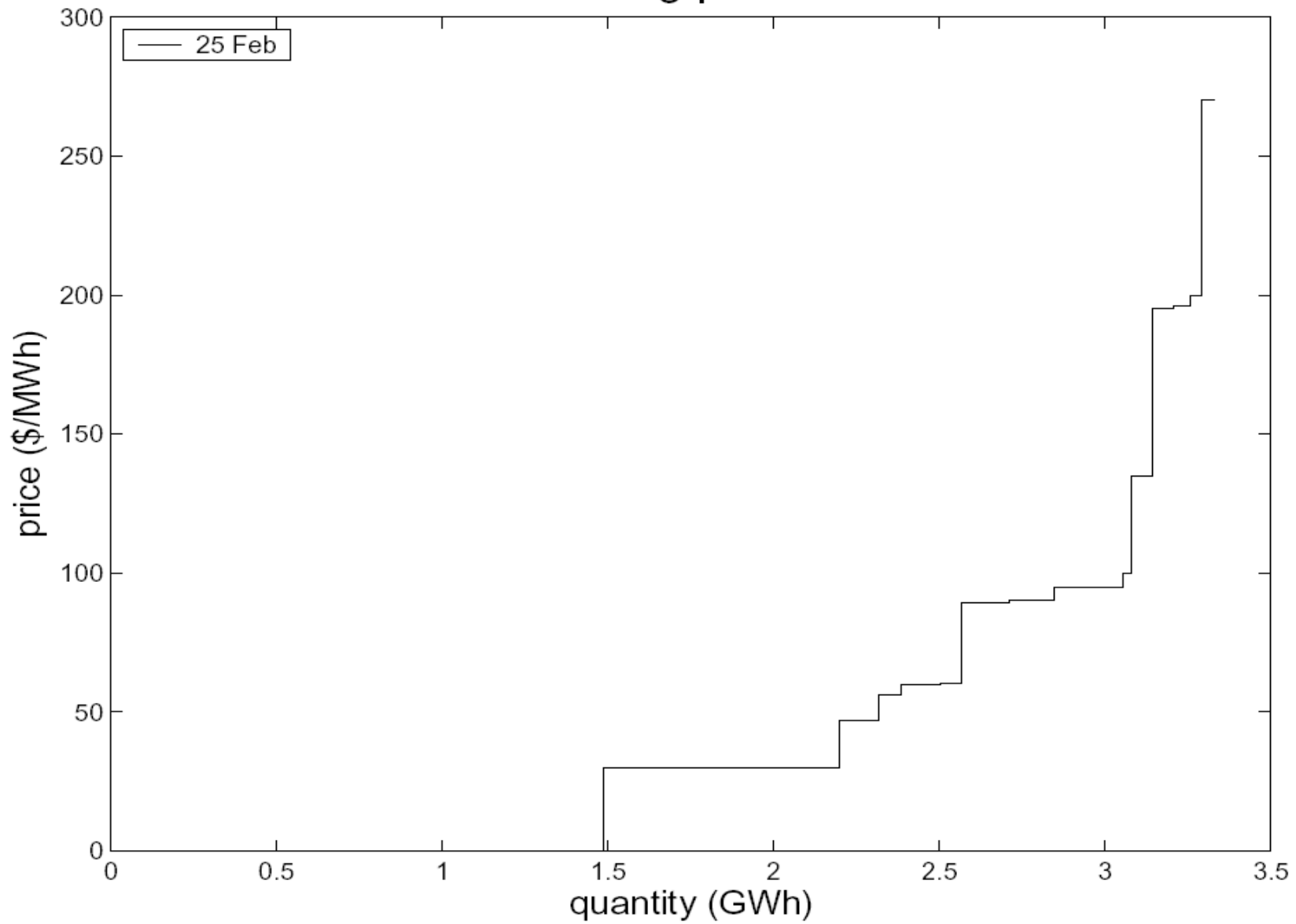
Offers by the main hydroelectric systems:

- [Manapouri](#)
- [Clutha](#)
- [Waitaki](#)
- [Waikato](#)

Daily offers from all stations



Combined morning peak stacks from Y



Inflow scenarios

- Use 70 years of historical data
- Direct method
 - policy must be constructed independent of test data
 - simulate over 60 years of out-of-sample years (or worst one)
- Synthetic data series (e.g. Gess)
 - estimate inflow process from data and then simulate
 - condition on recent history e.g. ENSO
 - can create many thousands of scenarios

Stochastic programming models

- Generator policies **prescribed** by model to minimize overall fuel cost
- SDDP is an example used in many centrally planned systems
- Infeasibility modelled by VOLL
- If infeasible then no policy will deliver security
 - insufficient generation in market
- If feasible, no guarantee of security (unless generation is prescribed)

Market equilibrium models

- Each generator's policy is chosen to maximize its expected profit
- Construct a Nash equilibrium of policies, where any single generator is optimizing assuming no changes in competitors' policies
- Simulate equilibrium policies to observe market outcomes

Single period model

Classical model (Cournot)

- Generator i offers quantity $Q(i)$ at price 0
- Demand elasticity determines clearing price
- Transmission network can be modelled
- Non identical players can be modelled
- Solve using calculus or commercial code

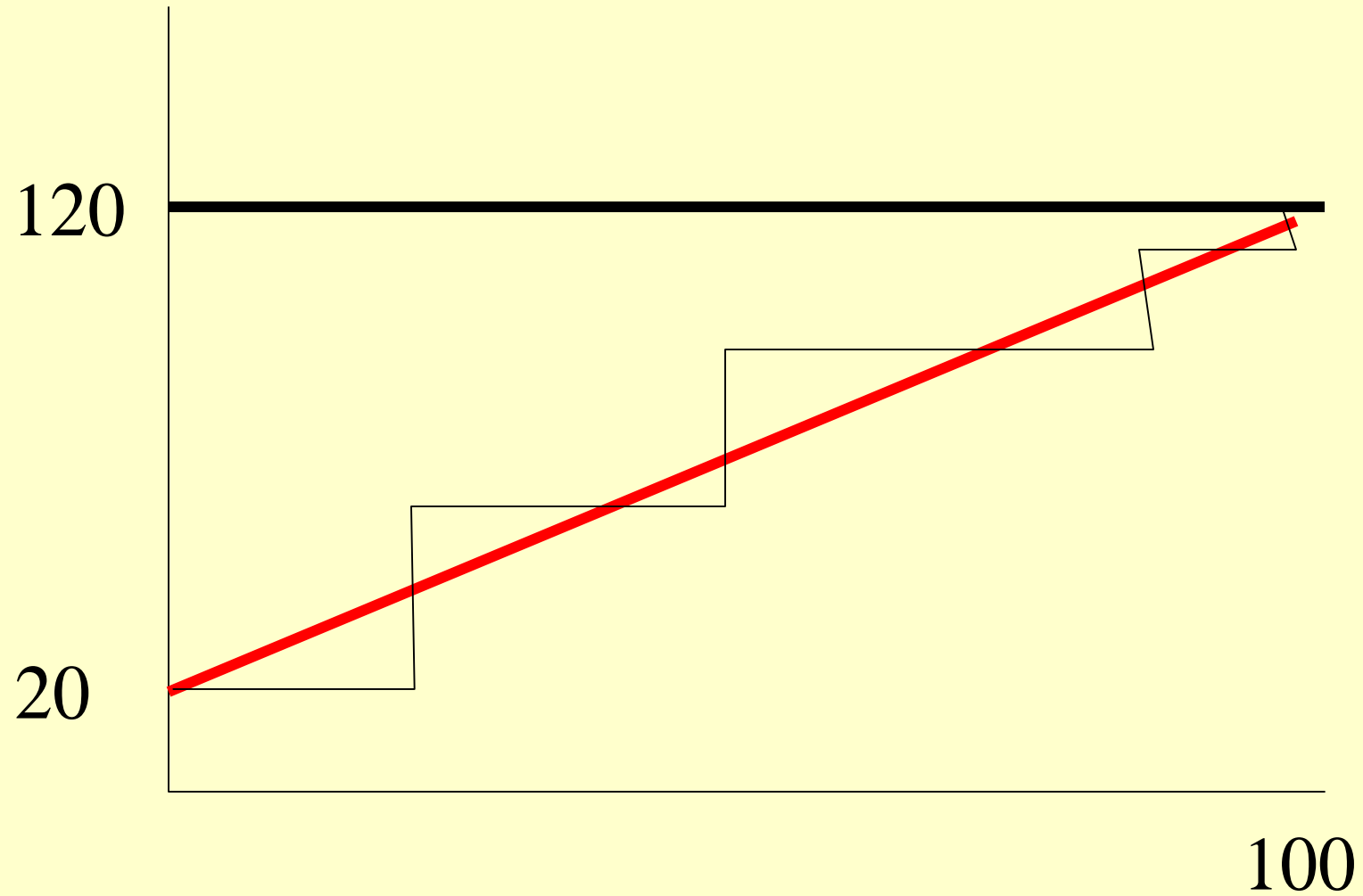
Supply-function model (Klemperer & Meyer)

- Players offer supply functions (stacks)
- Demand can be elastic or inelastic
- Uncertainty in demand
- Difficult to model and compute with

Supply function example

- Suppose the EC sets price cap of \$120
- Two competing generators with marginal cost \$20 and capacity 100 MW offer supply functions
- Demand randomly distributed on $[0,200]$
- Nash equilibrium stack (with infinite number of tranches) is the linear function $T(q)=q+20$
- Undercutting with a single tranche at \$119.99 is not optimal

Supply function example



Many periods-perfect information

- Cournot models only (to date)
- Solve a “multi-period mixed complementarity problem” using standard commercial software (MILES, PATH)
- Equilibrium is **static** and **here-and-now**
 - i.e. all players choose policies at start and adhere to them throughout planning period
- No account of uncertainty (e.g. inflows)

Dual dynamic programming algorithm

- Due to Scott & Read (1996), software exists (e.g. Dublin)
- Accounts for inflow uncertainty
- Compute equilibrium for final period T for all levels of state variables (e.g. reservoir levels)
- Compute profits for all players for all values of variables
- for $T-1$ and for all levels of state variables compute equilibrium accounting for profit function for $T-2$, and so on...
- Computationally expensive for more than 2 reservoirs

Simulation/optimization models

- BOOMER (Pritchard)
- Single period
- Model (uncertain) generator stacks by sampling from probability distributions
- Sample from stack distributions and demand distributions
- Solve (approximation of) SPD for every sample
- Construct optimal stack using dynamic programming for particular objective in mind

Example

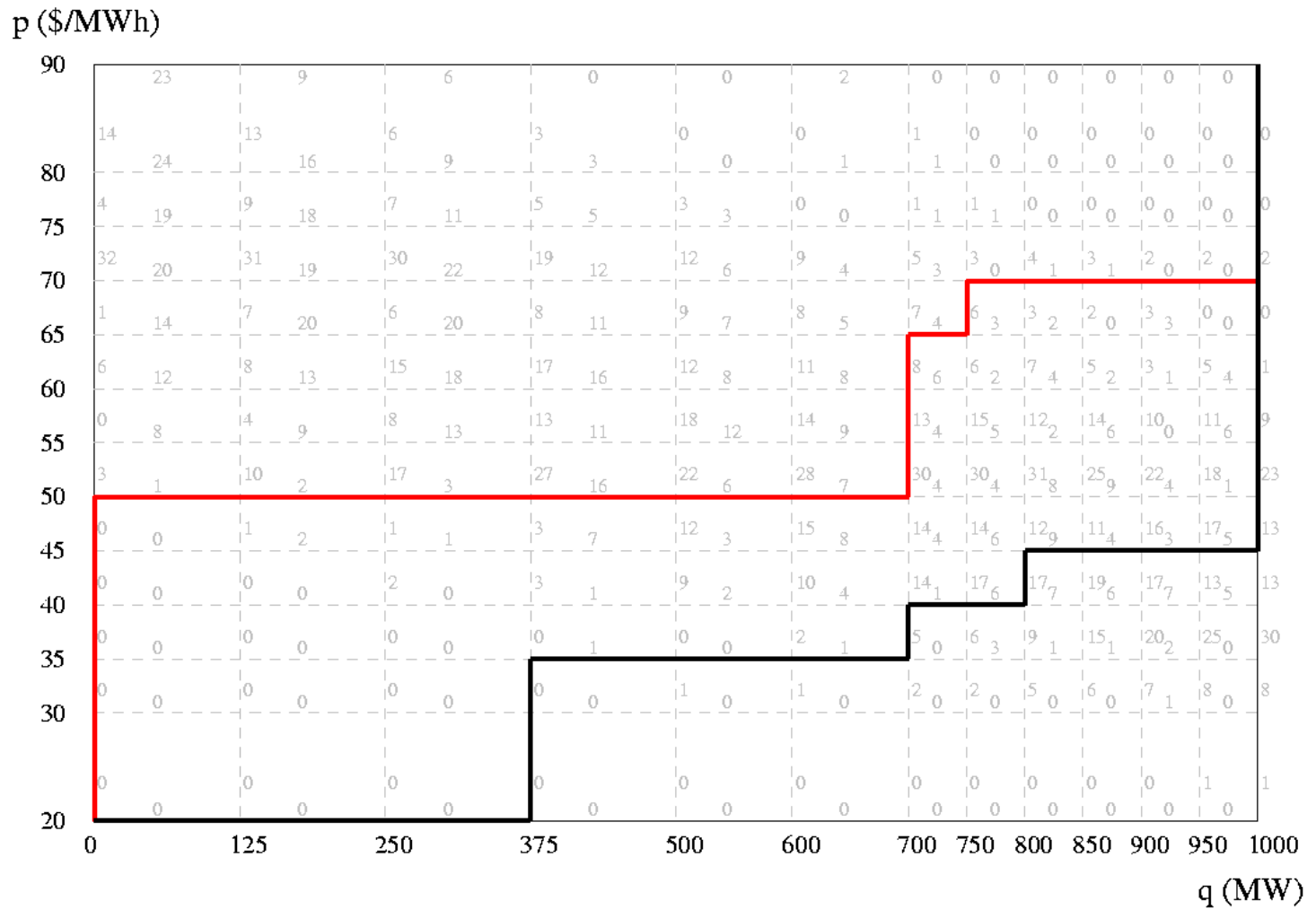
Find an offer stack to maximize

Gross revenue at HLY + TKU + RPO

- \$35/MW hr fuel cost at HLY
- cost of purchases to cover retail base of
 - 25% at MDN/HND/OTA/WKM
 - 10% at ISL/HWB

accounting for hedge contracts at \$50/MW hr of

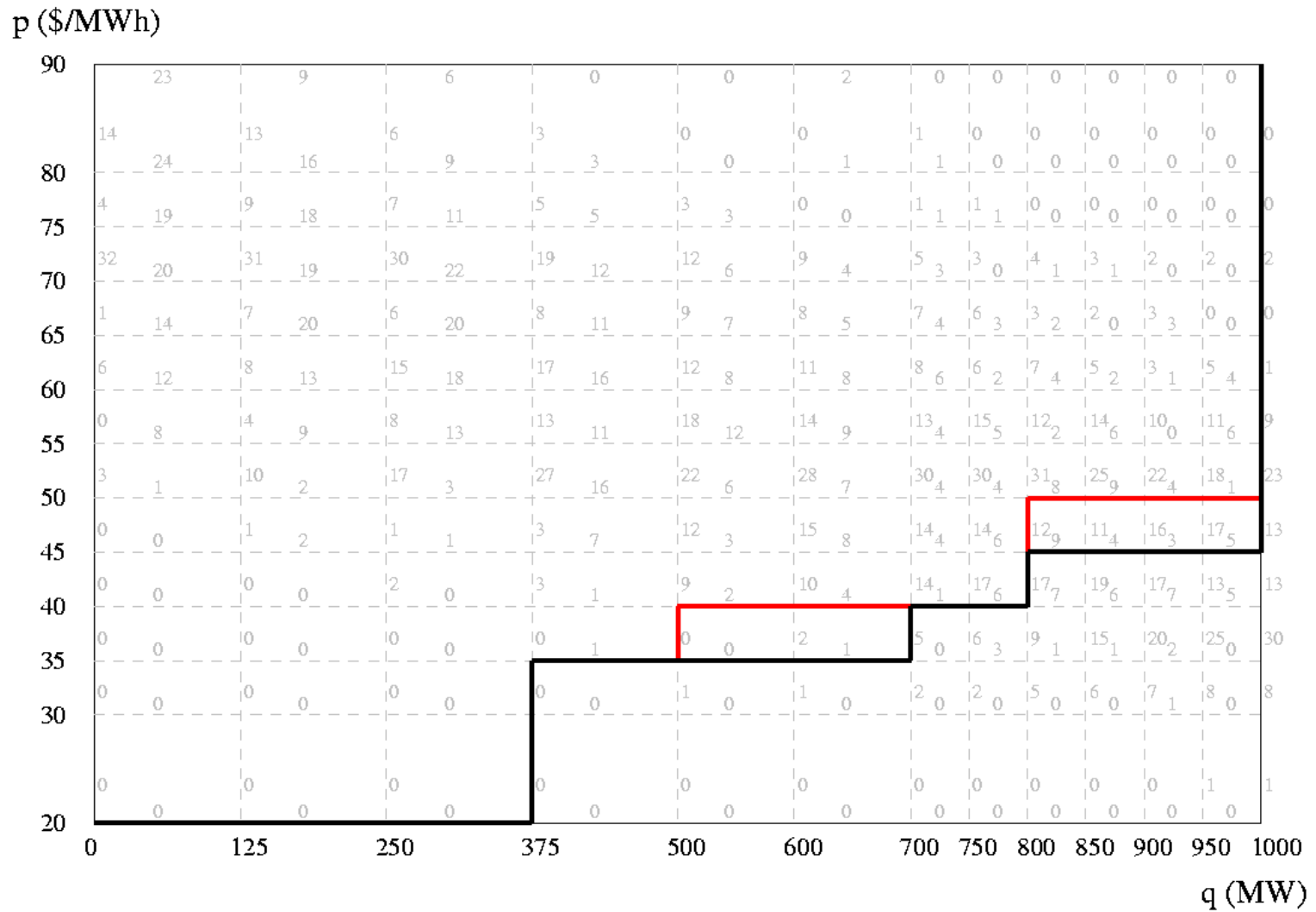
- 250MW at OTA
- 150MW at HAY
- 50 MW at HWB



Offers for HLY1

(no retail or hedges)

100 scenarios
 Expected value: 1937
 Expected value: 29602



Offers for HLY1

(retail customers move south)

100 scenarios

Expected value: 1937

Expected value: 1355

Objectives for the Electricity Commission

- (1) minimize Total Industry Levy
subject to $\text{Prob}(\text{Power Shortage}) \leq \text{Threshold} (=1/60)$

- (2) minimize $\text{Prob}(\text{Power Shortage})$
subject to $\text{Total Industry Levy} \leq \text{Budget} (=0.5c/\text{KWHr})$

- (3) minimize total extra cost to consumers
subject to $\text{Prob}(\text{Power Shortage}) \leq \text{Threshold} (=1/60)$

Implications of EC optimizing (1)

- Objective: minimize levy with security constraint
- No fixed offer price
- To offset levy
 - maximize profit from reserve subject to security
- The EC might seek to increase the spot price when they are on the margin...
 - more revenue for the EC...
 - but industry pays more overall

Implications of EC optimizing (2)

- Objective: minimize $\text{Pr}(\text{shortfall})$ within budget
- To meet budget the EC may have to maximize profit
- The EC might seek to increase the spot price when they are on the margin...
 - more revenue for the EC...
 - but industry pays more overall

Implications of EC optimizing (3)

- Objective: minimize total consumer cost with security constraint
- Difficult optimization problem to model and solve
 - Mathematical program with equilibrium constraints
- (3) gives the EC an incentive to keep prices low
 - should this be the function of the EC?
 - will this distort market signals?

Conclusions

- The EC needs to be precise in its objective
- Modelling choice can affect decisions, and hence outcomes
- The EC should use best modelling practice to ensure buy-in
- Uncertainty and market behaviour imply that EC decisions should adapt to circumstances as they emerge
- Market will adapt to the EC's policies
- Challenge: Can the EC inexpensively induce the market to operate to collectively ensure security?