Integrating Consumption and Reserve for Large Consumers in Electricity Markets

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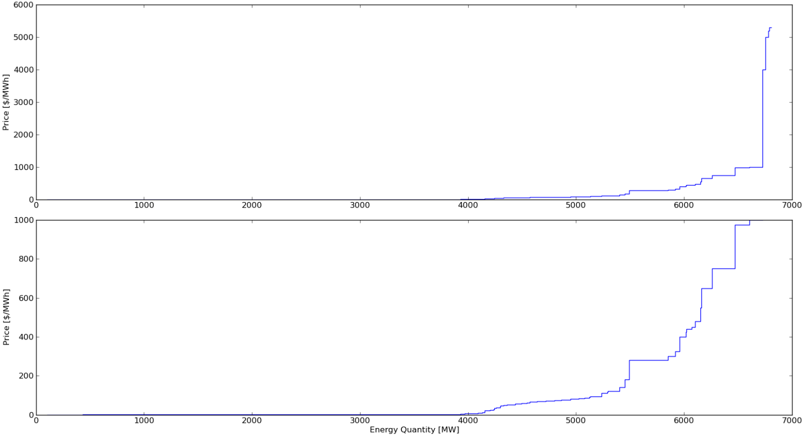
DEMAND RESPONSE

- Many different flavours of demand side participation, major energy users are potentially much lower hanging fruit than retail consumers.
- This talk will focus upon tools to assist these major energy users.
- *Bang for buck*
- Joint research with Golbon Zakeri, Geoff Pritchard and Brent Young.

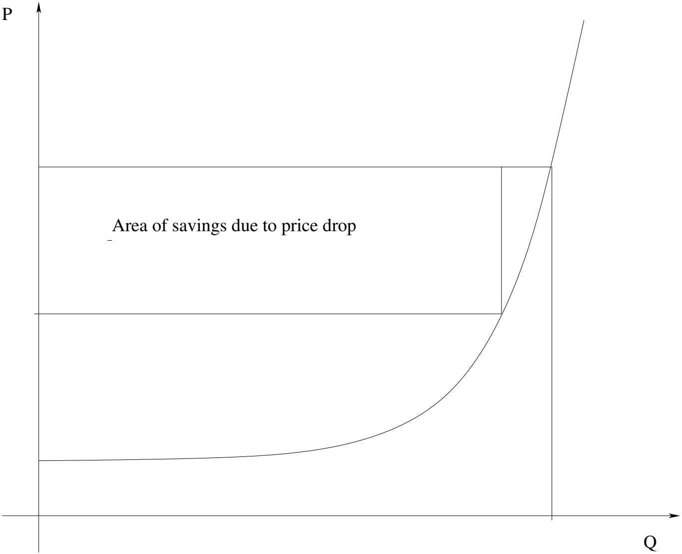
BACKGROUND

- Explicitly Co-optimised markets are becoming more common, e.g. NZ, MISO etc
- Energy and Reserve (Spinning Reserve or Interruptible Load (IL)) explicitly co-optimised with energy
- This can have some notable effects on prices and hence behaviour
- We needed to update our understanding of how prices work for spot exposed consumers

HOCKEY STICKS



POTENTIAL SAVINGS



A Small Problem

- NZ grid is large, over two hundred nodes
- The full mathematical formulation is 20+ pages
- We do have access to a full representation via the regulator (vSPD)

Solution

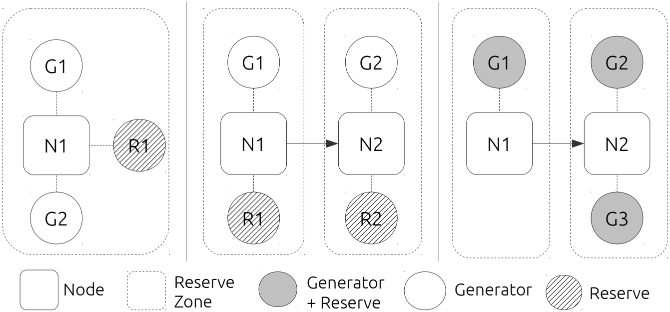
- Use a simple representation then expand from there
- Only include the constraints necessary
- "Cherrypick" parameters to induce constraints to bind

FORMULATION

$$
\begin{aligned}
[POPF]\ \min \quad & p_g^T g + p_r^T r & \\
\text{st.} \quad & Mg + Af = d & [\pi] \\
& r + g \le G & [\epsilon] \\
& r - Kg \le 0 & [\kappa] \\
& Er - g \ge 0 & [\lambda^1] \\
& Hr - Bf \ge 0 & [\lambda^2] \\
& r \le R & [\omega] \\
& |f| \le F & [\tau^{\pm}] \\
& Lf = 0 & [\alpha] \\
& r, g \ge 0 &
\end{aligned}
$$

$$
\begin{aligned}
[DOPF]\ \max \quad & d^T + R^T\omega + G^T\epsilon + F^T(\tau^+ + \tau^-) & \\
\text{st.} \quad & M^T\pi + \epsilon - K\kappa + \lambda^1 \le p_g & [g] \\
& \omega + \epsilon + \kappa + E\lambda^1 \le p_r & [r] \\
& A^T\pi + \tau^+ - \tau^- - B^T\lambda^2 + L^T\alpha = 0 & [f] \\
& \omega, \epsilon, \tau^{\pm}, \kappa \le 0 & \\
& \lambda^1, \lambda^2 \ge 0 &
\end{aligned}
$$

SIMPLE MODEL DIAGRAMS



RISK CONSTRAINED MARGINAL GENERATOR

- If we must cover $N - 1$ risk we must procure reserve to cover a large generator
- If this risk constrained generator is also the marginal price setting unit.
- *Procuring one more unit of energy requires the procurement of additional unit of reserve*

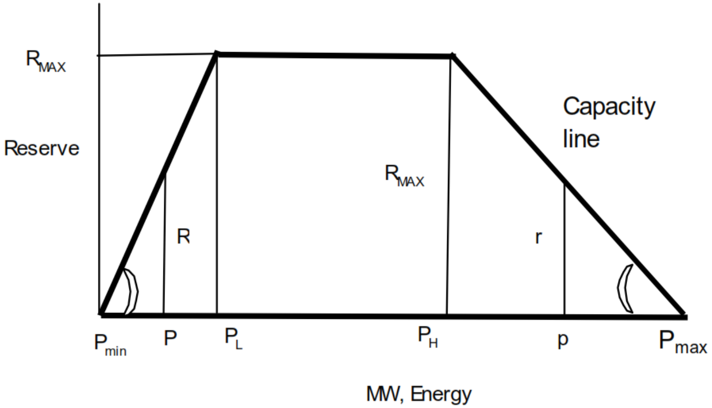
$$\pi = p_{g,marginal} + \lambda$$

RISK CONSTRAINED TRANSMISSION LINE

- The HVDC interconnection between the two islands is frequently a risk setter
- If flow is from South to North we have two options to meet an increase in demand:
  - Increase generation in the North
  - Increase generation in the South and Reserve in the North
- The implication being that the clearing price (energy) in the North is thus

$$\pi_N = \pi_S + \lambda_N$$

UNIT LEVEL CONSTRAINTS



PROPORTIONALITY CONSTRAINT

$$r - Kg \leq 0 \; [\kappa]$$

- What happens if the marginal reserve unit (price) cannot be feasibly dispatched?
- *To procure additional reserve requires the additional provision of energy*
- *Marginal clearing price becomes combination of*
  - Fractional quantity of reserve at Node 2
  - Fractional quantity of energy at Node 1
  - Fractional quantity of energy at Node 2

$$\pi_2 = \frac{1}{1 + k_{g,2}} p_{g,2} + \frac{k_{g,2}}{1 + k_{g,2}} (\pi_1 - \lambda_2)$$

Scheduling Pricing and Dispatch

- Every thirty minutes a network optimisation model is solved to determine the optimal dispatch of energy and reserve at each node in the market along with the clearing prices.
- Congestion, loop constraints, losses and reserve constraints *can* impact the market and prices.
- But do they in reality?

TESTS

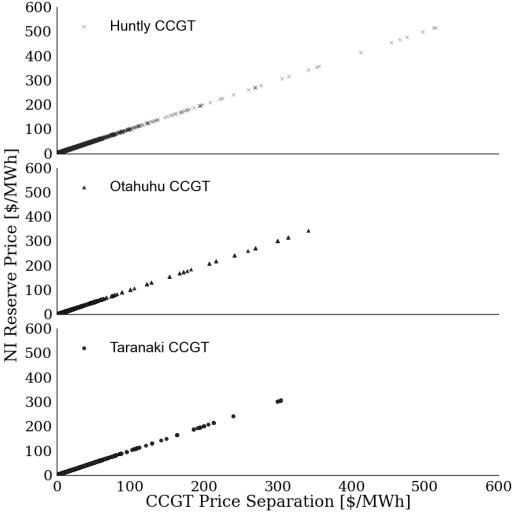
- Each of the small models can be formulated as an empirical test.
- If they meet the test it is *likely, but not definite* that they are reserve constrained

$$\pi_N - \pi_S = \lambda_N + L$$

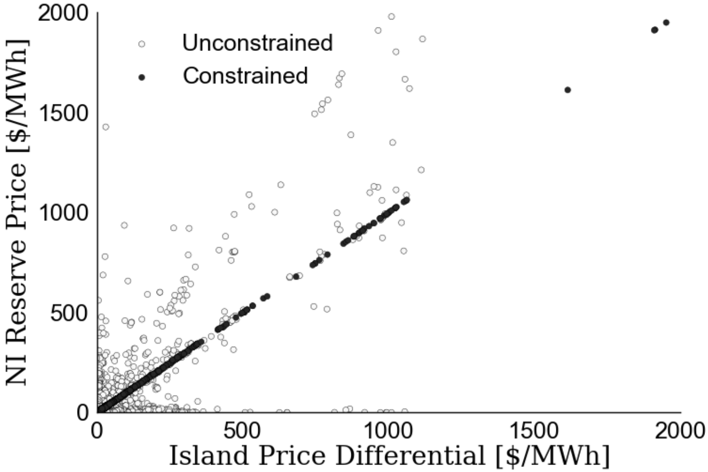
$$\pi_N - \pi_S - \lambda_N \leq \epsilon$$

$$\pi_N - \pi_S \geq \eta$$

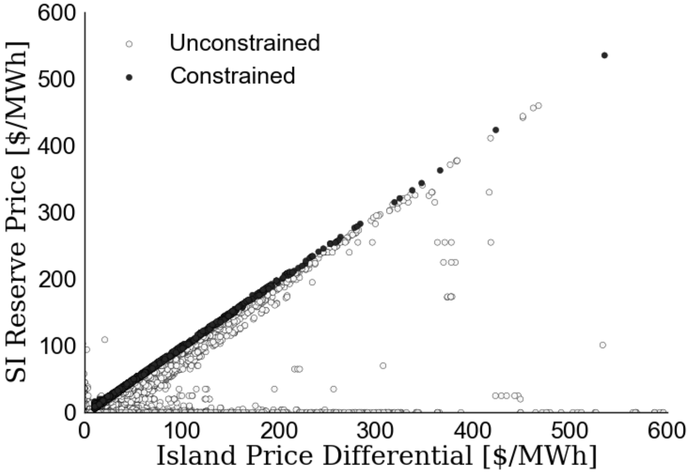
CCGT CONSTRAINT



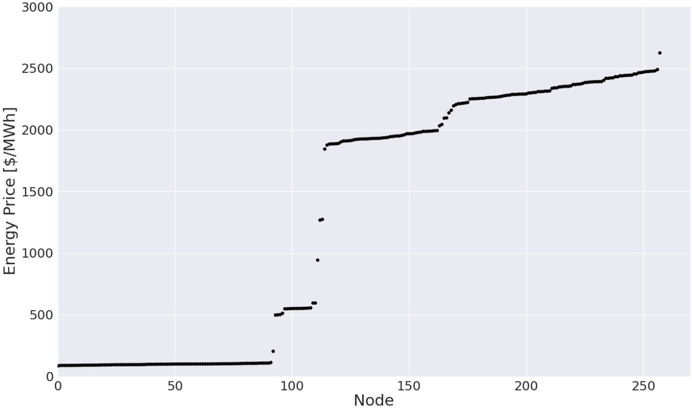
NORTHWARD FLOW CONSTRAINT



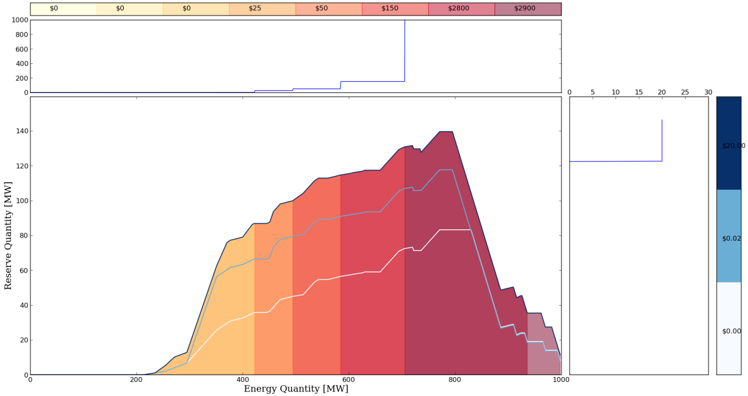
SOUTHWARD FLOW CONSTRAINT



NODAL PRICE SPLITS (OCT 3RD 2013: TP19)



VISUALISING ENERGY AND RESERVE OFFERS

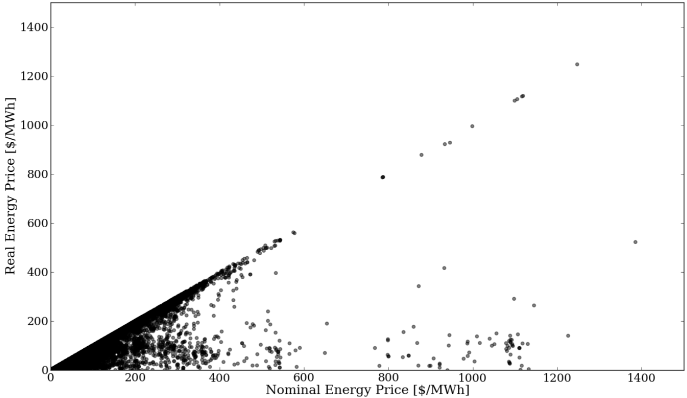


Large Industrial Consumers

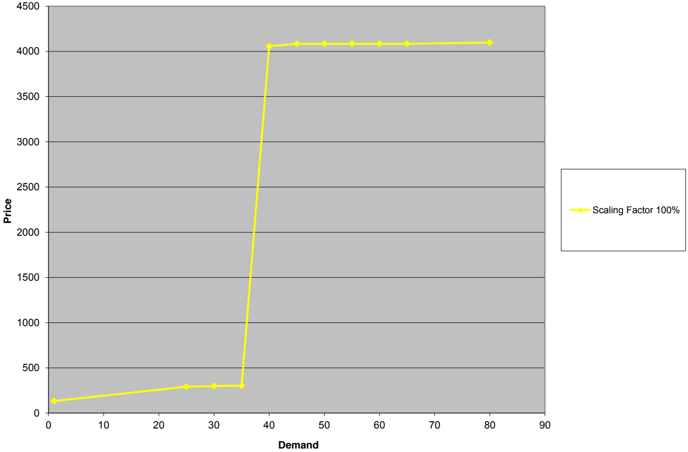
OVERVIEW

$$\pi - \lambda \quad vs \quad \pi$$

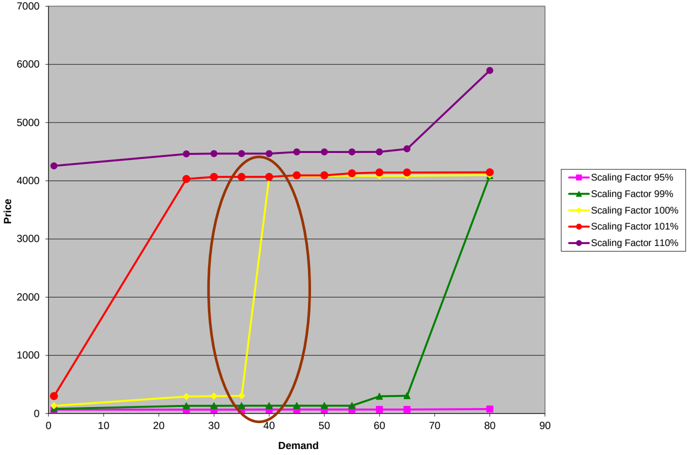
$$L = R$$



DETERMINISTIC PRICE RESPONSE



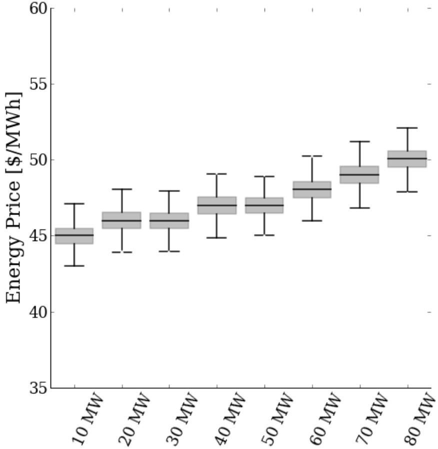
STOCHASTIC PRICE RESPONSE



BOOMER-CONSUMER

- Select a set of offers for the generators (e.g. historical)
- Use a distribution of load, e.g. log-normal
- Under different load scenarios simulate the energy price for different increments of the consumers load.

BOOMER-CONSUMER V1



Not real data, *cleaned up* for presentation purposes

WHAT ABOUT RESERVE

- Energy and Reserve prices are linked
- The Reserve strategy can thus be important due to the effect on energy prices
- We must also consider the revenue the consumer will make from offering reserves.

WHAT WE WOULD REALLY LIKE TO DO

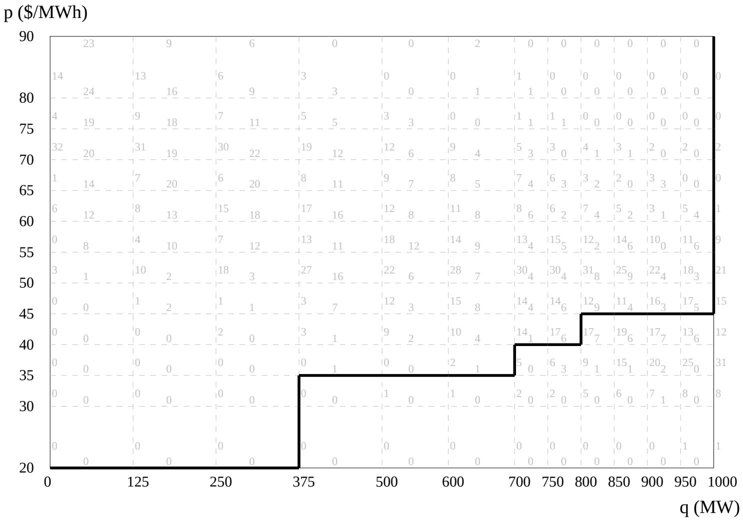
$$\max_{p^e=f(d), \quad p^r=g(r)} V(d, r, \pi^e, \pi^r)$$

subject to: Monotonicty + Market clearing

Of course too hard!

WHAT WE ACTUALLY DO

- Fix a level of demand
- Optimize over the reserve offer stacks
- Trace various residual demand curves in a grid (based on scalar multiple of overall NZ demand)
- Record energy prices
- Solve a *prize collecting* optimization (Dynamic Program) that delivers the optimal stack subject to the assumed grid.



100 scenarios
Expected value: 1937

- We now have a matching optimal reserve offer stack for each fixed level of demand.
- Can produce a distribution of prices for each demand level, but now with the optimal reserve offer in tact.
- We need to resolve the original stage of Boomer at this point to reproduce these distributions.

NEXT STEPS

- Co-optimize consumption and reserve offer (not for discrete choices of load as we do now).
- Build a price process and optimize the major user's production schedule over a time horizon.
  - Perhaps build a Markov process (time inhomogeneous) to govern overall load.
  - From that derive prices based on vSPD.
  - Use a stochastic dynamic program to come up with decisions on when to use and when to cut down on consumption of electricity.
- Develop a "rogue's gallery" of price periods to use when risk is a concern.
- Key issue is in the market offers, we can handle uncertainty in demand.

Thank You

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