Demand Response for Large Consumers of Electricity

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Introduction

- There are different flavours for demand side participation such as instigation of smart appliances.
- such ideas are great and many researchers work on them however there is potentially lower hanging fruit.
- This talk will focus on tools to assist major energy users with consumption and reserve offer decisions.

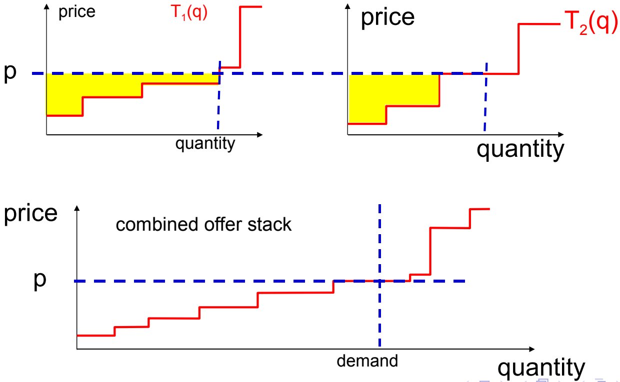
Introduction

- In 1996 NZ went from a centrally operated electricity system to an electricity market.
- Roughly 65% of generation is from hydro, the rest from thermal and wind (no nuclear) and none can be imported.
- In the market the generators offer quantities of electricity at given prices. The consumers put in consumption bids.
- A market clearing problem is then solved to determine the prices and quantities to dispatch from each generator.

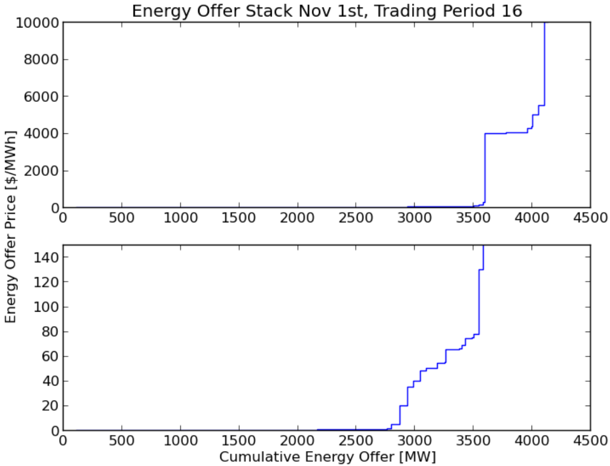
Example of an offer stack

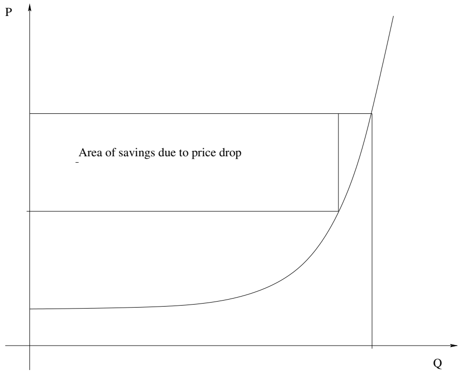
Uniform auction at a node

NZEM is a uniform price auction (e.g. single node)



Aggregated offer stack TP16, Nov 1, 2012





- Given the hockey stick nature of the stacks, response to price saves on the cut back part but also reduces price for the amount that is consumed.
- Fathoming price is key so we need a good understanding of dispatch.

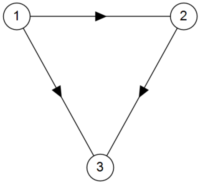
NZ transmission grid

- Owned, operated, and maintained by state-owned enterprise Transpower New Zealand Limited. In total, the national grid contains 11,803 kilometers (7,334 mi) of high-voltage lines and 178 substations.
- The HVDC Inter-Island is New Zealand's only high voltage direct current (HVDC) system, and links the North and South Island grids together.
- The NZ transmission grid (backbone) contains about 250 nodes and over 450 links.

The market clearing problem

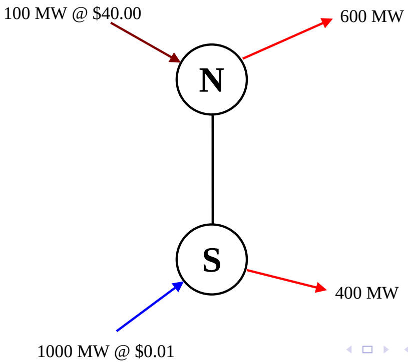
- The market clearing problem is set up so that the total cost of generation is minimized while the demand for electricity is met subject to all physical constraints.
- This is an *optimization* problem. (Often a linear or integer programming problem.)
- Such a solution delivers locational marginal prices for the different nodes.

Example of a market clearing problem

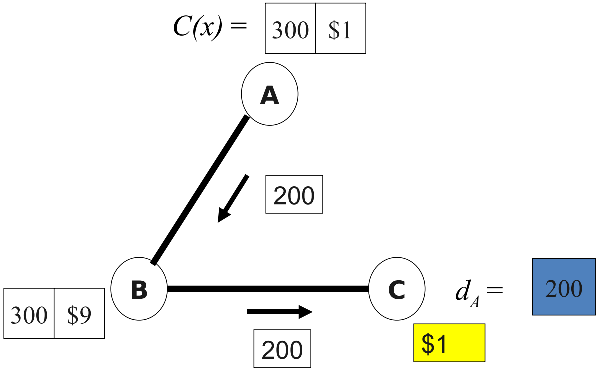


$$
\begin{aligned}
[3node - DP] \quad \min \quad & 0.01x_1 + 0.02x_2 + 10x_3 + 11x_4 \\
\text{s/t} \quad & x_1 + x_3 - f_{12} - f_{13} - \frac{\rho_{12}}{2} f_{12}^2 - \frac{\rho_{13}}{2} f_{13}^2 = d_1 \\
& x_2 + x_4 + f_{12} - f_{23} - \frac{\rho_{12}}{2} f_{12}^2 - \frac{\rho_{23}}{2} f_{23}^2 = d_2 \\
& f_{13} + f_{23} - \frac{\rho_{13}}{2} f_{13}^2 - \frac{\rho_{23}}{2} f_{23}^2 = d_3 \\
& \nu_{12} f_{12} - \nu_{13} f_{13} + \nu_{23} f_{23} = 0 \\
& -K \le f_{12} \le K
\end{aligned}
$$

Price separation – line congestion



Pricing: 1



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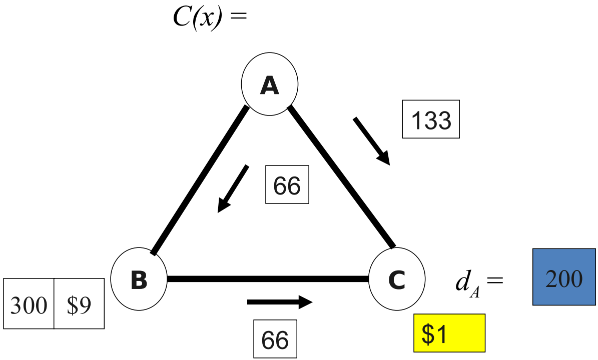
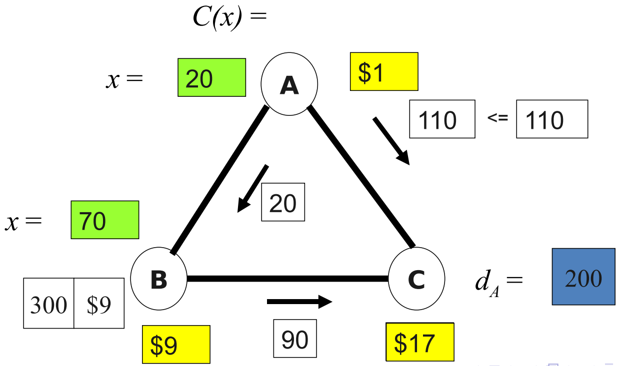


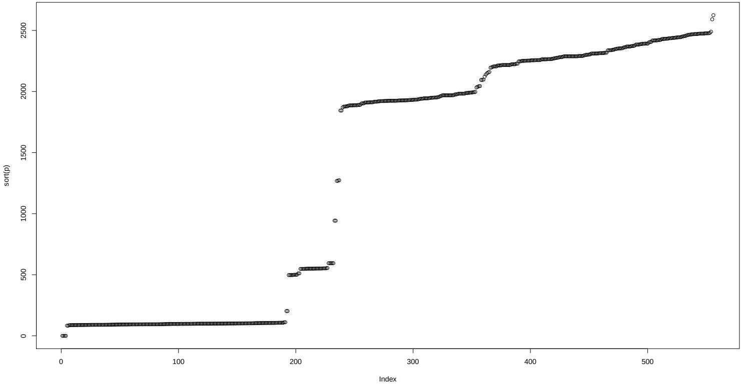
Springwasher effects



The heart of the market: Scheduling Pricing and Dispatch

- Every half hour of every day a network optimization problem such as the above is solved to determine the optimal dispatch of generation and the clearing price of electricity at each node of the market.
- Aside from already mentioned constraints, SPD makes reserve provisions as well.
- Furthermore, demand is stochastic, so actually every 5 minutes the solution is updated and there is also a frequency keeping station that follows the load.
- Congestion, loop constraints, losses and reserve *can* impact prices.
- However, do they really?

Nodal prices for October 3 period TP19



Analysis of the period

- South Island prices close to $100.00.

What's happening? (Answer and claim prize in the spirit of the festive season.)

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- Note neither the FIR price nor the high NI prices can be found in the stacks.

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- `ATI-OHK.1 *-1.235 + THI-WKM1.1 * 0.695` $\leq$ `476.99` is binding.

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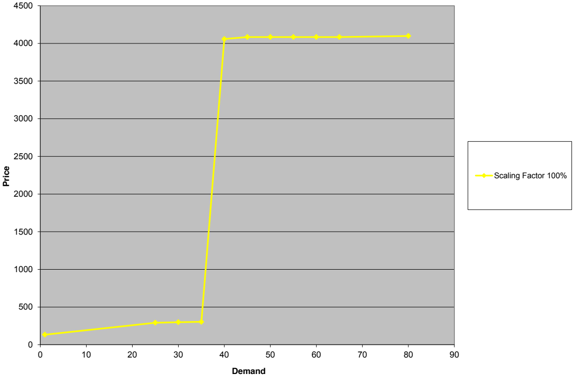
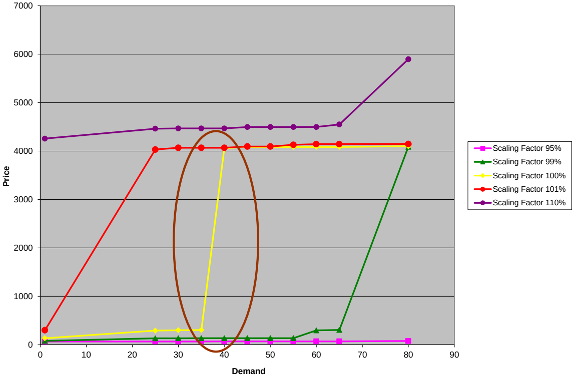
vSPD

- The *best approximation* to SPD is a software put out by the Electricity Authority called vSPD (vectorized SPD).
- It can be downloaded from
- `http://www.ea.govt.nz/industry/monitoring/models-and-tc`
- The software relies on having Microsoft Office, GAMS and a linear programing solver.
- Input data can also be obtained from the EAs website in gdx format.
- Great tool to explore what goes on in the market.

Price response – deterministic



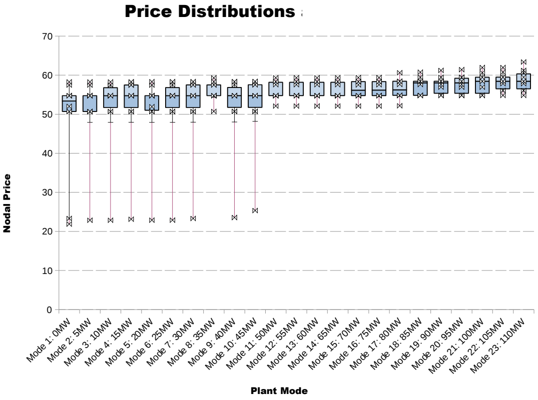
Price response – stochastic



BOOMER-consumer for consumption

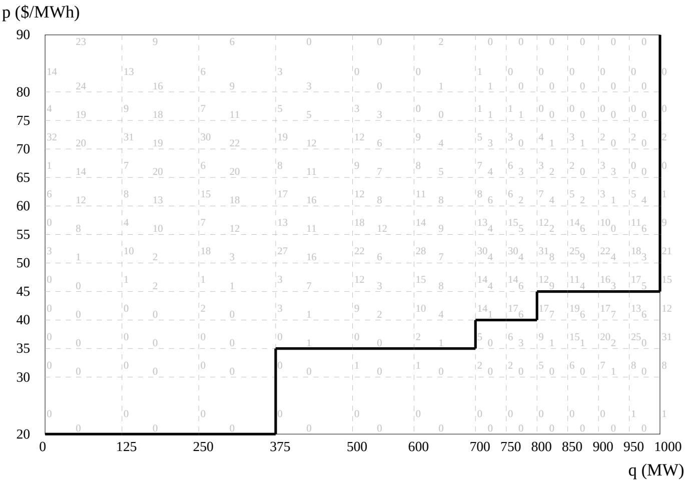
- select a set of offers from the generators (e.g. a historical period already provided by the EA).
- To deal with the uncertainty, have a distribution in mind for the load. For example a log-normal distribution applied to the total NZ load or NI and SI separately scaled.
- Under different load scenarios, simulate what energy price would result for increments of demand the major user consumes.

Boomer-Consumer v1



BOOMER-consumer complete with ILR

- select a set of offers from the generators (e.g. a historical period already provided by the EA).
- To deal with the uncertainty, have a distribution in mind for the load. For example a log-normal distribution applied to the total NZ load or NI and SI separately scaled.
- We then trace various residual demand curves (each based on a scalar multiple of overall NZ demand for instance) in a grid.
- We then solve a “prize collecting” optimization (a DP) that would deliver the optimal stack, subject to the assumed grid.



100 scenarios
Expected value: 1937

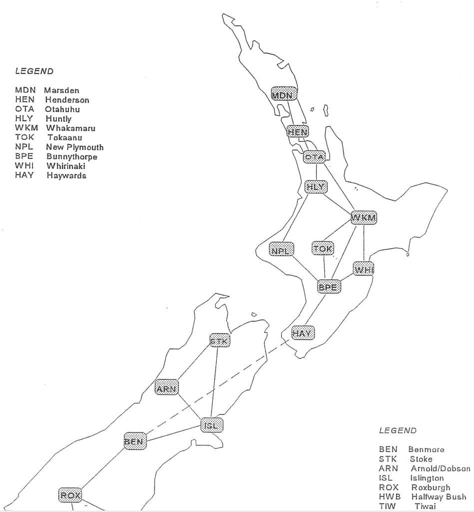
Next steps

- Co-optimize consumption and reserve offer (not for discrete choices of load as we do now). DEMON model.
- 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 "rogues' gallery" of price periods to use when risk is a concern.

Chewing the fat

As this is work in progress any comments or questions are most welcomed?

Simplified version of the NZ grid with only 18 nodes



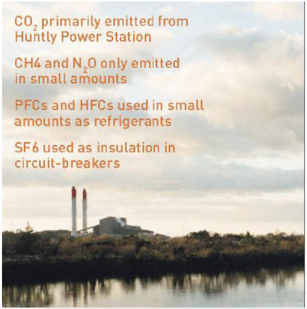
Generator's revenue optimization problem

- There are 2 different types of generators, those whose actions impact the price of electricity and those whose actions don't impact the price.

$$
\begin{aligned}
\max_{\{p_g, q_g\}} \quad & R(\pi_g, x_g) \\
\text{s/t} \quad & Mx + Af + Bf^2 = d \\
& Lf = 0 \\
& p^T + \pi^T M = 0 \\
& \pi^T A + 2\pi^T B D_f + \lambda^T L = 0 \\
& 0 \leq x \leq q \\
& \text{conditions on the stack, e.g. 5 tranches, etc}
\end{aligned}
$$

Modelling of the revenue optimization problem

- The problem in the previous slide is the very first cut in generator revenue optimization.
- Thermal generators need to consider load obligations, the cost of their fuel, any fuel contract mechanisms and unit commitment.
- They also need to consider environmental constraints.



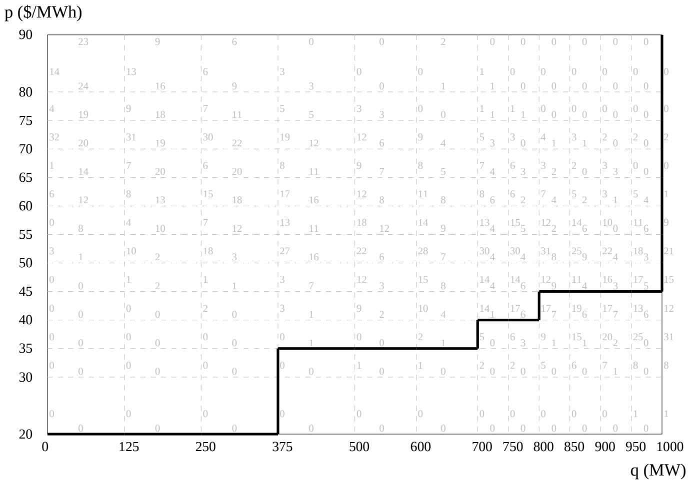
Modelling of the revenue optimization problem

- A hydro generator may need to run a river chain to keep the river balanced and keep within allowed minimum flow requirements. Reservoir levels also have minimum and maximum allowed levels.

- The unit commitment and running the river constraints make the optimization problems in different periods tied and this adds a whole new dimension of complexity.

Uncertainty

- So far we have assumed that each generator knows the demand and the actions of other generators. However this is definitely not true! So a better approximation is to cater for uncertainty.
- The concept of a residual demand curve and why we have offer stacks in the market.
- MLE estimation of the market distribution function. BOOMER software.



100 scenarios
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Demand side optimization

- Major users of electricity see the spot price and can respond to it by reducing demand.
- These market participants not only have to pay the spot price of electricity but they also have to pay for line charges.
- Line charges are incurred through periods of peak usage.

$$\begin{array}{lll} \min & PM & + \sum_{t \in T} (c_t - p_t) s_t \\ \text{s.t.} & \sum_{t \in T} s_t & \leq S \\ & s_t & \leq a_t \\ & \sum_{t \in \tau} (d_t - s_t) & \leq M \qquad \text{for all } |\tau| \leq k \end{array}$$

Distribution company's optimization problem

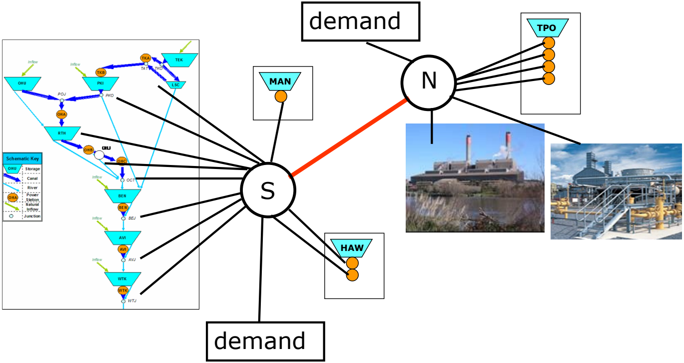
- Related to the consumer's problem is the revenue optimization for the distribution company.
- Here the distribution company will want to decide on optimal tariffs taking into account the response that the consumer will make to those tariffs.
- The optimal tariffs will maximize profits that come from earned revenue minus the cost of network expansion.
- Network expansion is determined from the peak usage of consumers.

Steady state behavior of the market

- The Wolak report commissioned by the NZCC.
- What Wolak concluded and some debate.
- This is allocative efficiency.
- How does one measure (approximately) productive efficiency.

Stochastic program to cater for optimal central planning

Case study: NZ model



Some of what remains to be done

- Full blown market participant optimization problems.
- Models that capture the stochastic process of electricity prices.
- Consumer participation: smart meters, designing a system on how to pass the prices down.
- Tools that assess the impact of regulatory change on the market.
- Models that explore the optimal investment for electricity infrastructure including the transmission grid and generation assets.