Reserve in Electricity Markets

Nigel Cleland
University of Auckland
EPOC

February 18, 2014

Introduction

About Me

- University of Canterbury, BE(Hons) Chemical and Process Engineering
- University of Auckland, Year Three, Ph.D Eng. Sci and C&M
- Prior work at load aggregators
- HVDC Pole 3 Commissioning (Trading Team)
- Based at Transpower S.O. 2013
- Various Consulting Jobs

ROUGH AGENDA

- Reserve Constraints
- Assessment of Spot Prices
- Equilibrium Models of Reserve Participants
- Visualising Energy and Reserve Offers
- Using Bayesian Probability to assess Constraints
- Open Source and Open Data

Reserve Constraints

IT STARTS WITH A PICTURE

Figure : Haywards Nodal Spot Price (x axis) compared with the North Island FIR Price (y axis)

Why does this matter?

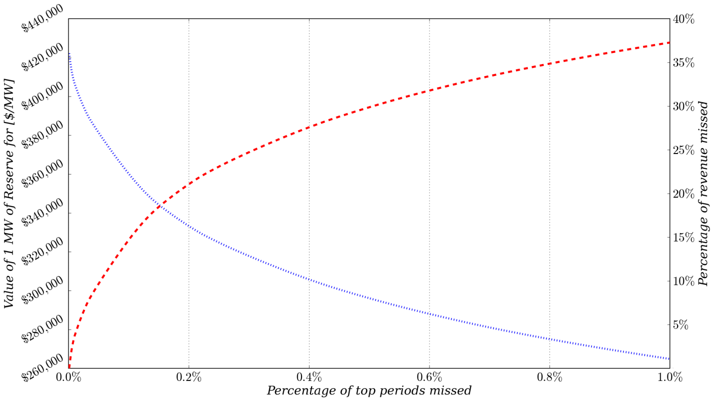

Figure : Revenue “lost” for missing highly priced trading periods

Effect on Individual Consumers

Table : Monthly Revenue “missed” by various IL producers

	NZST	PPAC	SKOG
2009	18-85%	2-92%	30-80%
2010	4-90%	0-90%	5-70%

In November 2010 NZST missed 90% of the monthly IR Revenue, SKOG missed 6%

SOME THEORY

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

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

CASE STUDIES

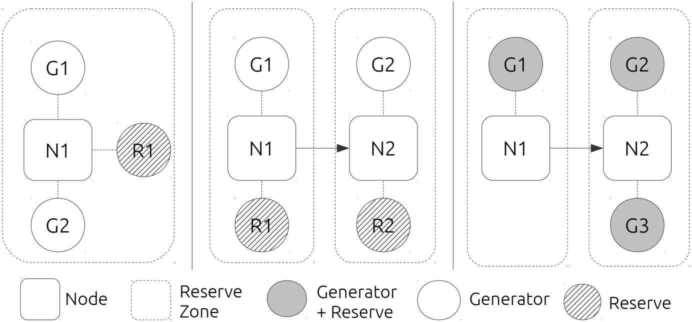

Figure : Some Case Studies to illustrate different mechanisms of binding constraints occurring

CASE STUDY RESULTS

Marginal Risk Setting Generator

$$\pi = p_{g,marginal} - \lambda \quad (1)$$

Risk Constrained Transmission Line

$$\pi_2 = \pi_1 - \lambda_2 \quad (2)$$

Bathtub Constrained Transmission

$$\pi_2 = \frac{1}{1 + k_{g,2}} p_{g,2} + \frac{k_{g,2}}{1 + k_{g,2}} (\pi_1 + \lambda_2) \quad (3)$$

TESTING THESE, MARGINAL GENERATOR

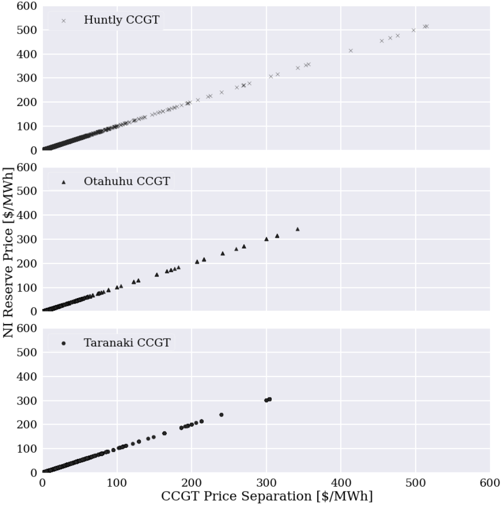

Figure : Reserve Constraints binding upon major CCGT Units

Testing These, Marginal Transmission, NI

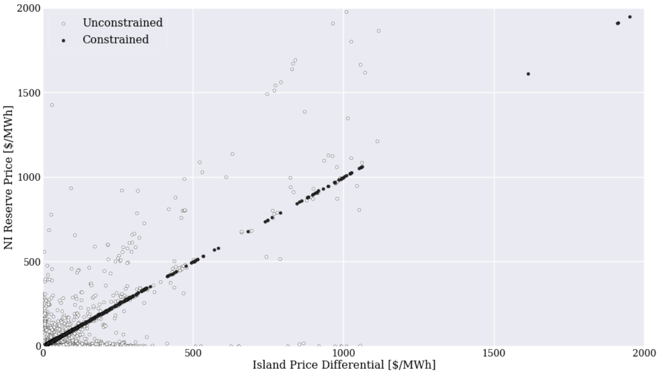

Figure : Reserve Constraints Binding upon Northward HVDC Transmission

Testing These, Marginal Transmission, SI

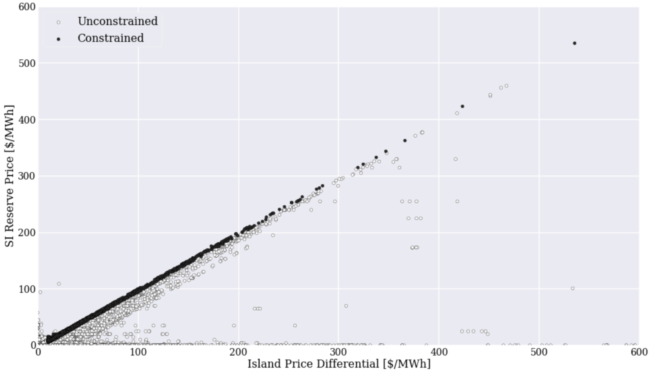

Figure : Reserve Constraints Binding upon Southward HVDC Transmission

TESTING THESE, BATHTUB CONSTRAINTS

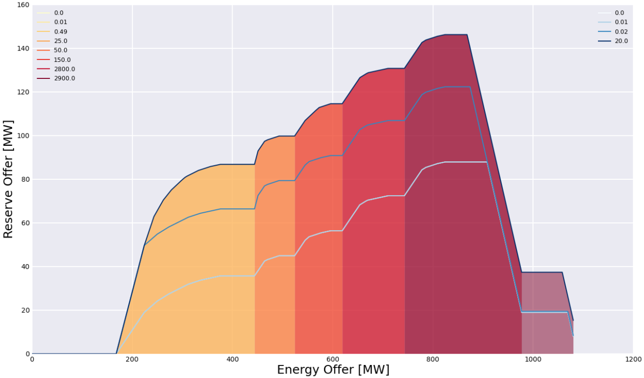

Figure : Mighty River Fan Curve, TP 19, October 3 2013.

Spot Market Prices

SCARCITY, CONSTRAINTS OR BOTH?

- How do we understand Price?
- Moving up a merit order stack?
- High Demand = High Price?
- Hydrology? Price = f(Inverse Hydro)
- Constraints?

Average Price at Different Demand

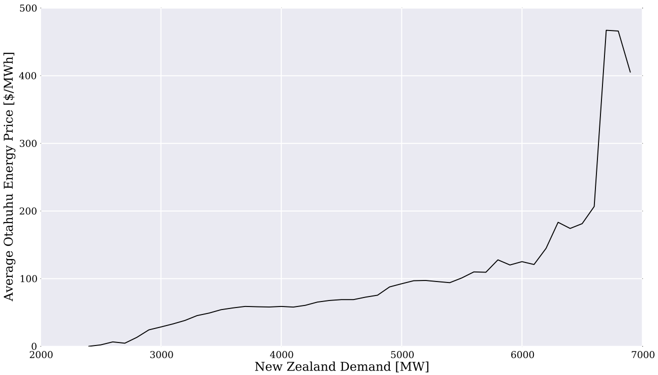

Figure : The higher the demand, the higher the energy price, we're moving up the stack.

Average Price at Different Hydrology

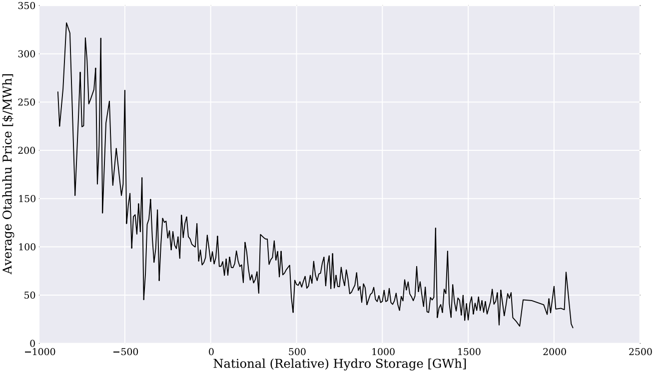

Figure : As expected, the less water we have (relative to the lower decile for the time of year) the higher the average price

Average Demand at Different Price Points

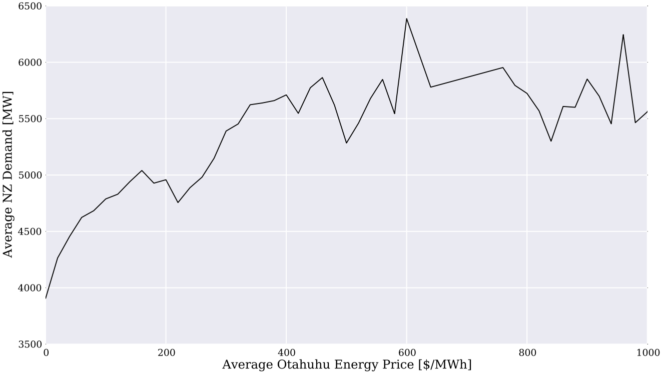

Figure : The relationship between high demand and high prices isn't so clear when the reverse situation occurs

Average Hydrology at Different Price Points

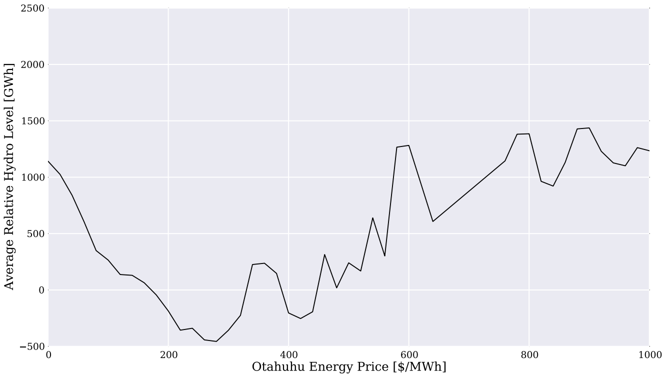

Figure : The Paradox of Hydrology, the highest price trading periods are associated with large quantities of water

Constraints at different price levels

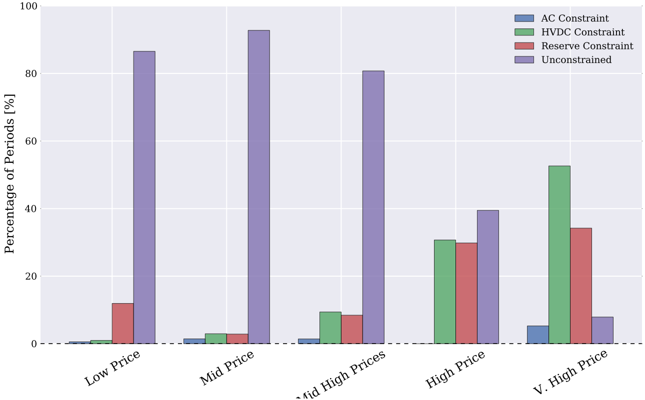

Figure : Aggregate assessment of constraints in the New Zealand Market

Specific Constraints

Table : Constraints binding during the top 155 priced trading periods

	Occurences	Mean	Min	Max
Waikato Block SIR Constraint	41	768	0	4948
Waikato Block FIR Constraint	40	491	2	3834
Tokaanu SIR Constraint	26	417	2	1010
Waikato Block Dispatch	21	1409	13	4653
Tokaanu FIR Constraint	13	1009	0	4409

Contextualising the Constraints

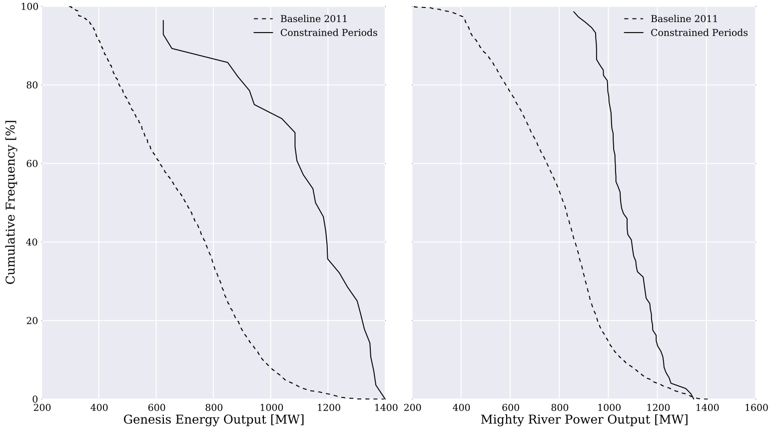

Figure : Dispatch (CDF) of Genesis and Mighty River during Constraints Periods (Genesis for Tokaanu Constraints, Mighty River for Waikato Constraints) compared with the overall CDF for the providers

Equilibrium Models

OVERVIEW

- Equilibrium Models give insight into how providers will act under simplified assumptions.
- Often used in market power assessments (e.g. UK/USA)
- Integrating Reserve Markets is difficult
- Some Prior art, but not as relevant to NZ.
- Use Linear Supply Functions

GENERATOR PROBLEM

$$
\begin{aligned}
C(g_{n,i}) &= (\beta_{n,i} + 0.5\gamma_{n,i}g_{n,i})g_{n,i} \\
C(r_{n,i}) &= \alpha_{n,i}r_{n,i} \\
R(c) &= \sum_{n,i} \lambda_n g_{n,i} + \sum_{n,i} \mu_n r_{n,i} \\
\pi(c) &= \sum_{n,i} (\lambda_n - \beta_{n,i} - \gamma_{n,i}g_{n,i})g_{n,i} + \sum_{n,i} (\mu_n - \alpha_{n,i})r_{n,i}
\end{aligned}
$$

SETTING UP THE EQUILIBRIUM

- Want to Maximise Profit
- Generator specifically takes into account how they influence the others
- Introduce a Leader - Follower problem
- ISO acts as a Follower
- Introduce KKT conditions as constraints to the Generator Problem

ISO PRIMAL PROBLEM

$$
\begin{array}{rcr}
\min & \sum_{n,i}(\beta^*_{n,i} + 0.5\gamma^*_{n,i} g_{n,i}) g_{n,i} + \sum_{n,i} \alpha^*_{n,i} r_{n,i} & \\
\text{st} & \sum_{i \in n(i)} g_{n,i} + \sigma_n f = d_n & \forall n \\
 & \sum_{i \in n(i)} r_{n,i} - \sigma_n f \geq 0 & \forall n \\
 & 0 \leq g_{n,i} \leq G_{n,i} & \forall n, i \\
 & 0 \leq r_{n,i} \leq R_{n,i} & \forall n, i
\end{array}
$$

ISO Dual Problem

$$\begin{aligned}
\max \quad & \textstyle\sum_n d_n \lambda_n - \sum_{n,i} 0.5 \gamma^*_{n,i} g^2_{n,i} & \\
\text{st} \quad & \lambda_n \le \beta^*_{n,i} + \gamma^*_{n,i} g_{n,i} & \forall n, i \\
& \mu_n \le \alpha^*_{n,i} & \forall n, i \\
& \textstyle\sum_n \sigma_n (\lambda_n - \mu_n) = 0 & \forall n
\end{aligned}$$

ISO COMPLIMENTARITY CONDITIONS

$$
\begin{aligned}
g_{n,i}(\beta^*_{n,i} + \gamma^*_{n,i} g_{n,i} - \lambda_n) = 0 \quad \forall n, i \\
r_{n,i}(\alpha^*_{n,i} - \mu_n) = 0 \quad \forall n, i \\
\mu_n\Big(\sum_{i \in n(i)} r_{n,i} - \sigma_n f\Big) = 0 \quad \forall n
\end{aligned}
$$

Full Problem Definition

$$
\begin{aligned}
\max \quad & \textstyle\sum_{n,i}(\lambda_n - \beta_{n,i} - 0.5\gamma_{n,i}g_{n,i})g_{n,i} \\
& \quad + \textstyle\sum_{n,i}(\mu_n - \alpha_{n,i})r_{n,i} \\
\text{st} \quad & \textstyle\sum_{i\in n(i)} g_{n,i} + \sigma_n f = d_n && \forall n \\
& \textstyle\sum_{i\in n(i)} r_{n,i} - \sigma_n f \geq 0 && \forall n \\
& 0 \leq g_{n,i} \leq G_{n,i} && \forall n, i \\
& 0 \leq r_{n,i} \leq R_{n,i} && \forall n, i \\
& \lambda_n \leq \beta^*_{n,i} + \gamma^*_{n,i} g_{n,i} && \forall n, i \\
& \mu_n \leq \alpha^*_{n,i} && \forall n, i \\
& \textstyle\sum_n \sigma_n(\lambda_n - \mu_n) = 0 && \forall n \\
& g_{n,i}(\beta^*_{n,i} + \gamma^*_{n,i} g_{n,i} - \lambda_n) = 0 && \forall n, i \\
& r_{n,i}(\alpha^*_{n,i} - \mu_n) = 0 && \forall n, i \\
& \mu_n(\textstyle\sum_{i\in n(i)} r_{n,i} - \sigma_n f) = 0 && \forall n
\end{aligned}
$$

Why would I do this

- I'm a Masochist?
- Theoretical Insights can lead to interesting conclusions
- Help explain the why, not just the what
- Publishable

PRELIMINARY RESULTS

- "Blocking" behavior has been observed
- When blocked the other participant will seek to equalise prices.
- Pre HVDC upgrade Meridian self withholding to not induce HVDC reserve constraints
- "Optimal" was most likely for them to generate 200-300 MW more at times
- Increase in MW leads to a decrease in price at your node, self defeating
- How much do you care about the efficient use of water

Visualising Energy and Reserve Offers

UNDERSTANDING TRADEOFFS

- Reserve and Energy are linked
- Unit Capability
- Energy Price
- Reserve Price
- Security Constraints can be very important

THE INVERSE BATHTUB

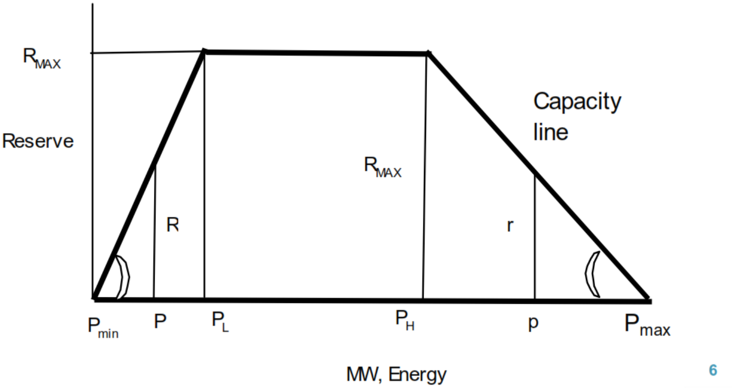

Figure : Depiction of the technical constraints limiting energy and reserve offers, proportionality, capacity, unit capability constraints, Bhujanga Chakrabarti, System Operator

FLAWS WITH THE REPRESENTATION

- Technically Feasible does not imply Economically Feasible
- No consideration of price
- Single Unit Representation

IMPROVING THE REPRESENTATION

- Energy Prices and Reserve Prices are important
- Combinations are importants

Single Unit

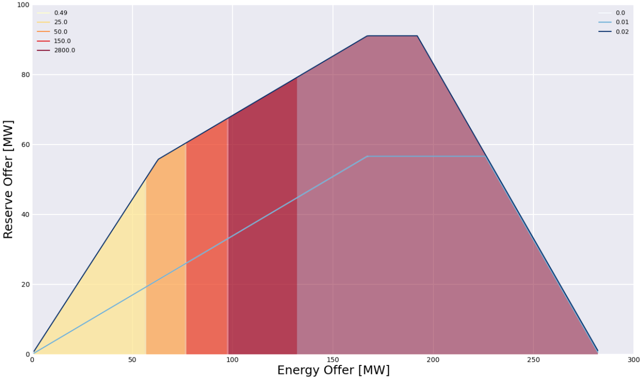

Figure : Representation of the Fan Offered for Maraetai for TP19

Single Company

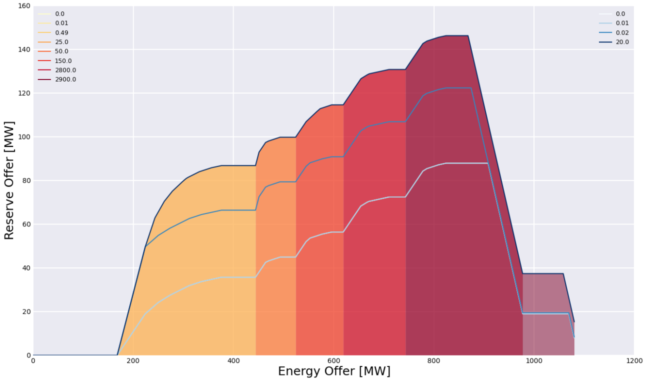

Figure : Representation of the Fan offers by Mighty River Power for TP19

ENTIRE ISLAND

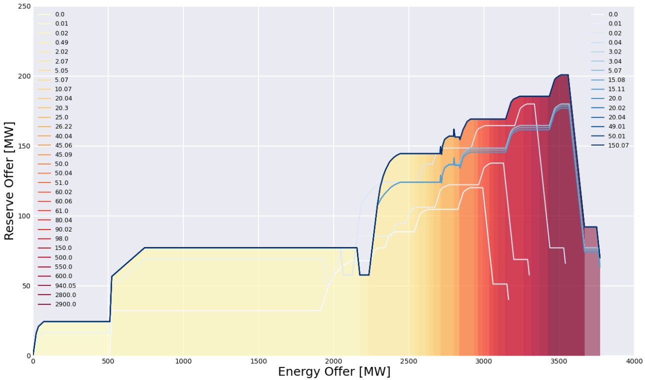

Figure : Full Representation of the North Island Offer Fan for TP19

HOW THIS WORKS

- Create an incremental capacity line for each unit of (1MW increments) linked with energy price.
- For each reserve pairings create a corresponding incremental reserve line bound by the bathtub constraints.
- Do a little bit of book keeping for the combined capacity constraint.
- Produce a number of station fans which can then be filtered and grouped based upon reserve price.
- Create a separate "fan" for each reserve price and offer.

HOW THIS WORKS V2

- Take a subset of the stations
- Filter by each unique reserve price
- Group by each unique reserve price, offer precedence to higher ratio units
- Sort by energy price, reserve price, reserve ratio
- Plot it (Actually it's dozens of automatically generated plots merged together)
- Cross fingers it doesn't break

Issues and Future Improvements

- Interruptible Load Offers
- Tail Water Depressed Offers
- Overlay Energy and Reserve Clearing Quantites
- Multiple technology types don't play well.

Intended Use Cases

- Instances of “withholding” reserve by pricing energy out
- Useful Visualisation for market strategies
- HVDC transfer operations (identifying feasibility)
- Meridian Trading Optimisation Problem
- Priority?

Bayesian Probability and Constraints

What conditions

$$P(\text{Constraint}|\text{State of the World})$$

States of the World

- Primary
  - Hydrology
  - Time of Year
  - Time of Day
- Derived
  - Price
  - Demand
  - Availability

HYDROLOGY

Problem: Hydrology is not evenly distributed, very chunky
Solution:

$$\begin{aligned} P(C|H) &= \alpha P(C| \geq H) + (1-\alpha) P(C| \leq H) \\ \alpha &= 1 - \frac{n}{N} \end{aligned}$$

WHAT DOES THIS LOOK LIKE

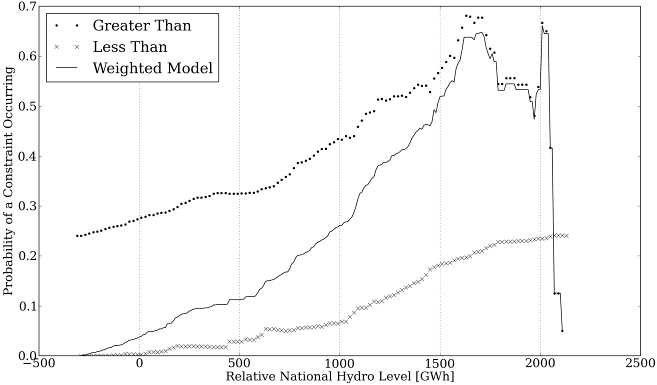

Figure : Illustration of the weighting procedure for assessing constraints as a function of Hydrology, time of year (Summer) and time of day (Peak)

FITTING THIS INFORMATION

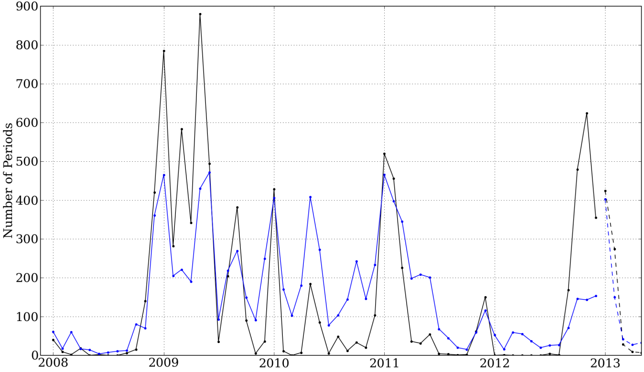

Figure : Fitting the model to fitted historical data (solid line) and unfitted historical data (dashed lines).

RESULTS AND FLAWS

- Can predict constraints in aggregate, no information about price
- Identifies periods which are "sensitive" to reserve
- Haven't had time to formalise the methodology
- Work was done prior to HVDC commissioning
- Appears to overweight low probability periods.

Open Source and Open Data

Why Open Source?

Opaque Analysis and Trust

Regulators create winners and losers

Why Open Data

Access to data fires collaborations

Ideas can come from external and internal places

Thank You

nigel.cleland@gmail.com