An Agent-Based Model of the NZEM: Predicting Prices and Policy Outcomes

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Overview

- Traditional approach to modelling electricity markets
  - Some recent policy debates in New Zealand
- Agent-based modelling
  - Example: Erev-Roth Algorithm
  - Commercial uses of agent-modelling
- Designing an agent-based model for New Zealand
  - Network Data
  - Calibration
- Some very preliminary results

Electricity Market Models

- Historically, models of electricity markets could be broadly divided into two categories (Ventosa et al. 2005)

Computational Competitive Models

- Firms bid their true marginal costs
- Often have extremely detailed network constraints and generator parameters
- Include capacity constraints and long-term investment decisions
- e.g. GEM, PLEXOS (both used in NZ)

Electricity Market Models

- Historically, models of electricity markets could be broadly divided into two categories (Ventosa et al. 2005)

Theoretical Equilibrium Models

- Full strategic (profit-maximising) behaviour assumed
- Based on Cournot or Supply Function equilibria
  - (approximating the step supply function bids used in reality)
- No network constraints or capacity constraints
- Linear or quadratic cost functions

Electricity Market Models

Computational Competitive Models

- Useful for
  - Least cost generation planning
  - Security of supply issues

- But less useful for
  - Determining the impact of policies in the presence of market power (particularly when the policy is aimed at reducing market power!)

Electricity Market Models

Theoretical Equilibrium Models

- Useful for
  - Market power analysis (prices, welfare) under different market designs

- But less useful for
  - Determining the impact of any kind of policy when transmission constraints are present
  - Theoretical models tend to lose pure strategy equilibria when you add constraints, or the results are different from the no-constraint case

Recent New Zealand Policy Debates

Will asset swaps spur more competition amongst generators?

- The upcoming swap
  - Genesis to own Tekapo A & B, Meridian to own Whirinaki
- Aim is to lower prices by spurring more competition amongst generators
  - More firms will own generation in the South Island
  - More firms will own hydro and thermal generation assets

Recent New Zealand Policy Debates

Who should pay for the HVDC upgrade?

- Current transmission pricing methodology requires the South Island generators to pay for the HVDC upgrade (Electricity Commission, 2008)
- Thinking is that the HVDC gives SI generators access to NI demand
- This ignores benefits to NI generators, and benefits to NZ consumers from potential greater competition and greater security of supply

Agent-Based Modelling

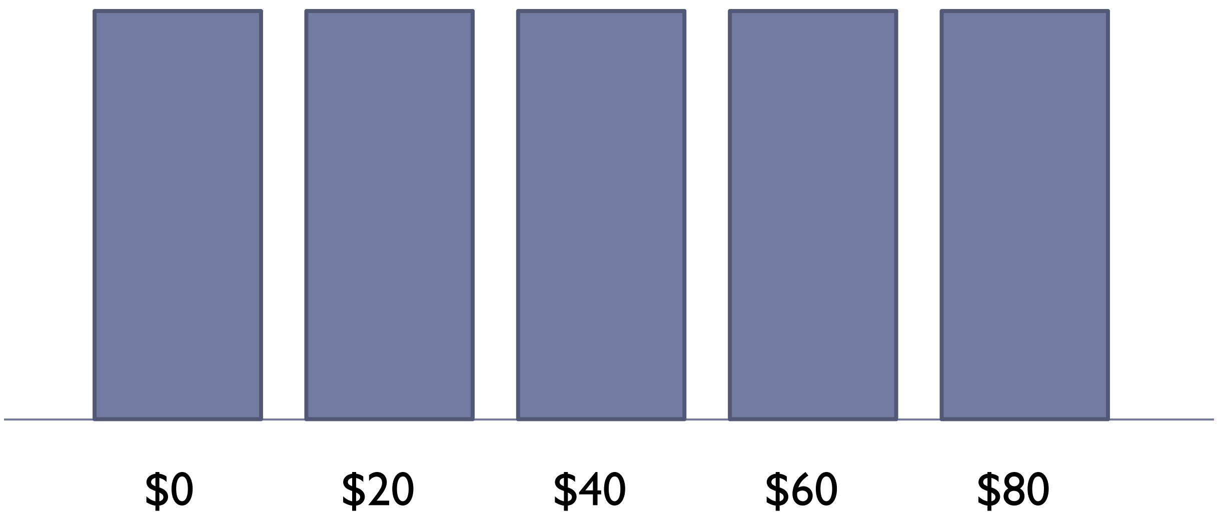
- Agent-based models are simulation models
  - Allows for very realistic network representations
- Each player in the model is represented by an *agent*
  - Usually some type of learning algorithm
- Agents typically have limited rationality and limited market information. Instead they assign choice probabilities to their possible actions and update these probabilities based on actual market outcomes over time
  - They don't just blindly bid at cost each period

Erev-Roth Algorithm

- A reinforcement learning algorithm
- Proposed by Erev & Roth (1995), based upon learning principles from the psychology literature
- Erev & Roth (1998) demonstrated that this algorithm could track successfully the behaviour of human subjects in 12 different multi-agent repeated games with unique equilibria

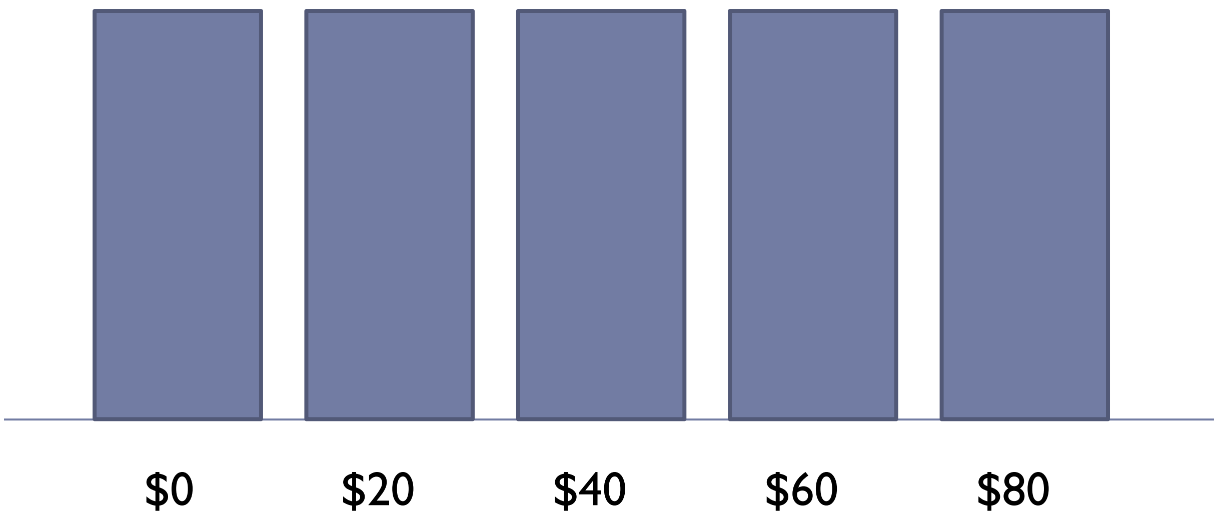
Erev-Roth Algorithm

- Each generator starts with a ‘propensity’ to choose any given action (think of it as a weight on each action). In the first period, every action is equally likely.



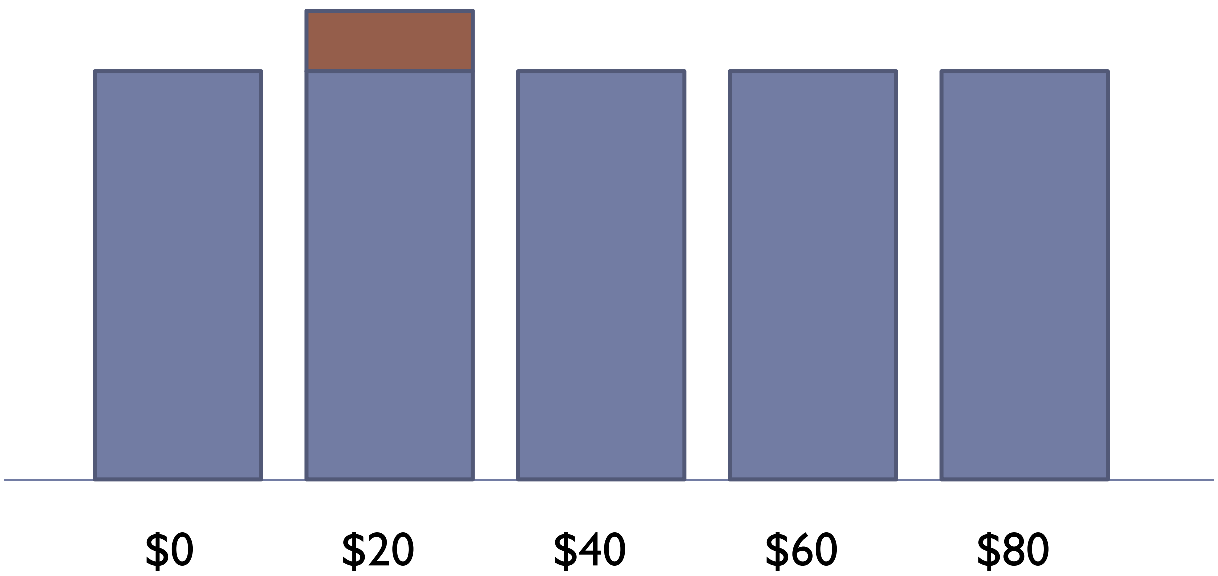
Erev-Roth Algorithm

- Say the firm chooses $20, all the other firms independently choose an action, and the market is then cleared.



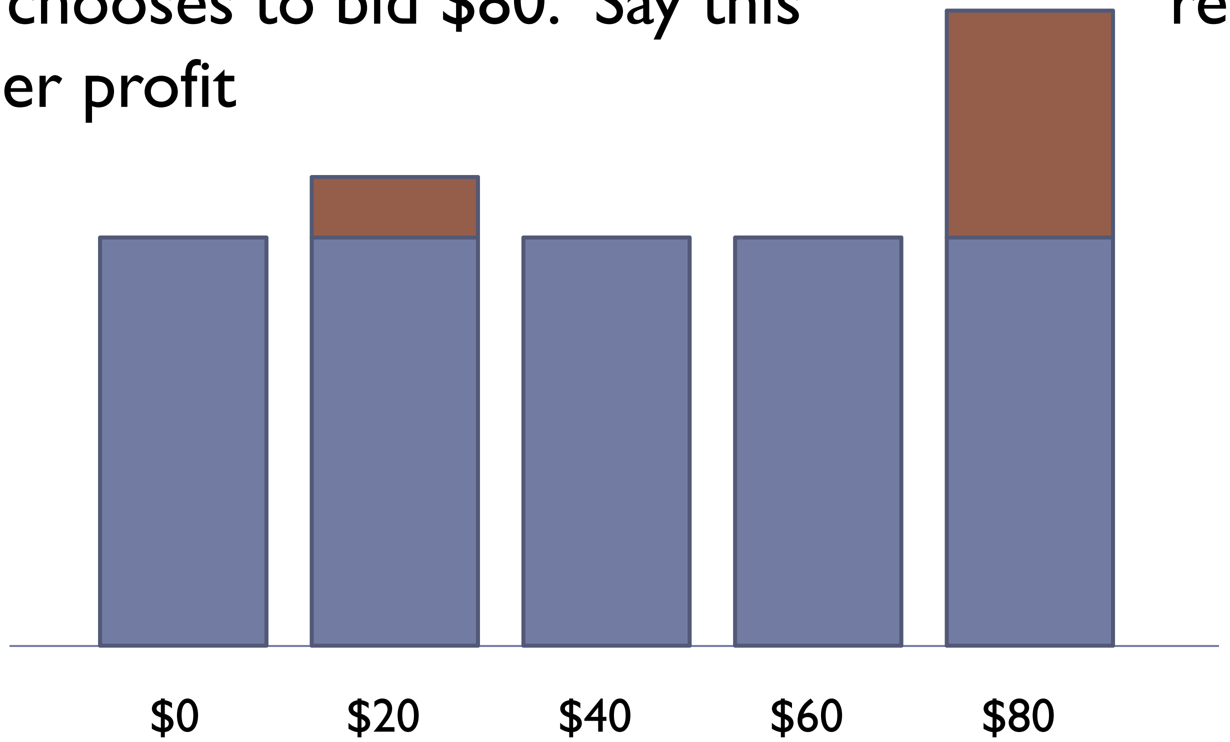
Erev-Roth Algorithm

- The most basic form of the algorithm is simply to add that profit to the propensity for the action '$20'



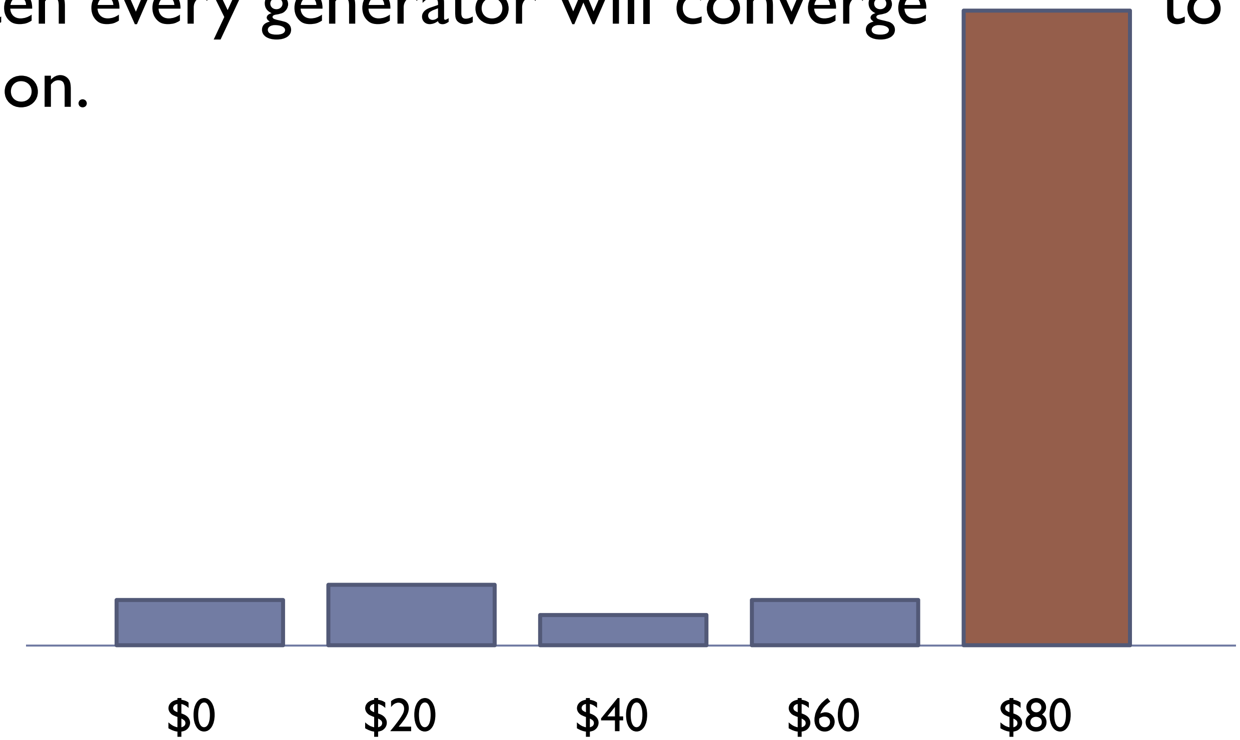
Erev-Roth Algorithm

- Suppose in the next period, the firm takes a random draw and chooses to bid $80. Say this returns a higher profit



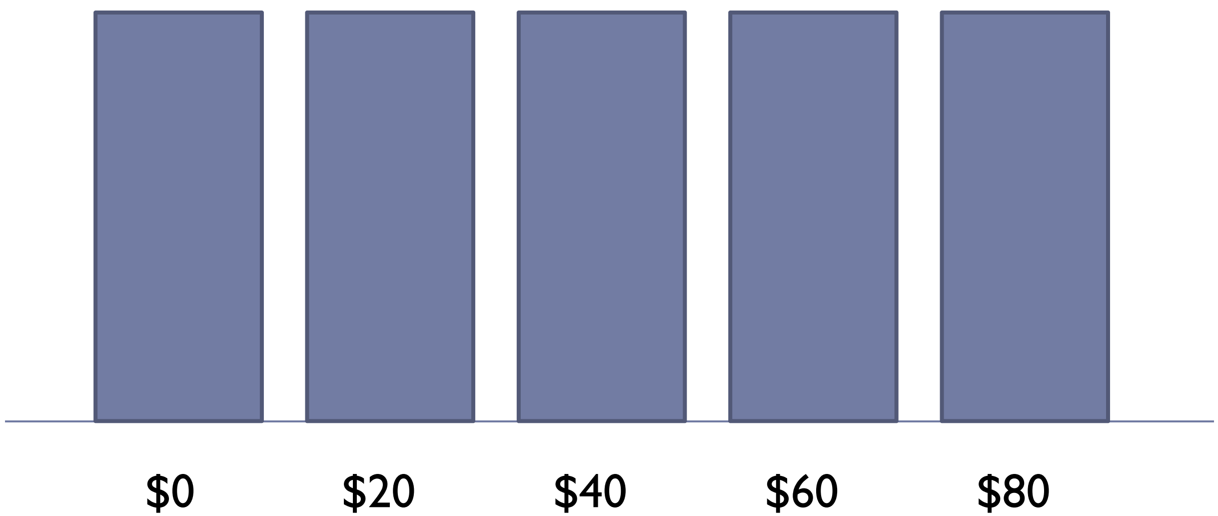
Erev-Roth Algorithm

- Algorithm repeats for a specified number of periods. Often every generator will converge to a single action.



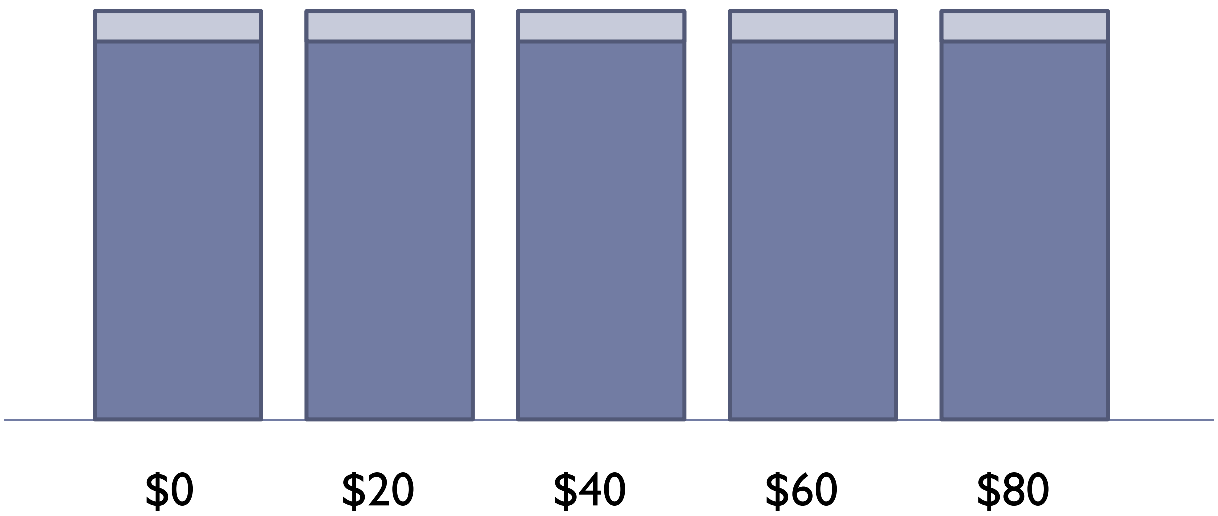
Erev-Roth Algorithm

- This is not the complete algorithm . We also have a recency (r) parameter and an experimentation (e) parameter. Suppose the generator chooses $20 again.



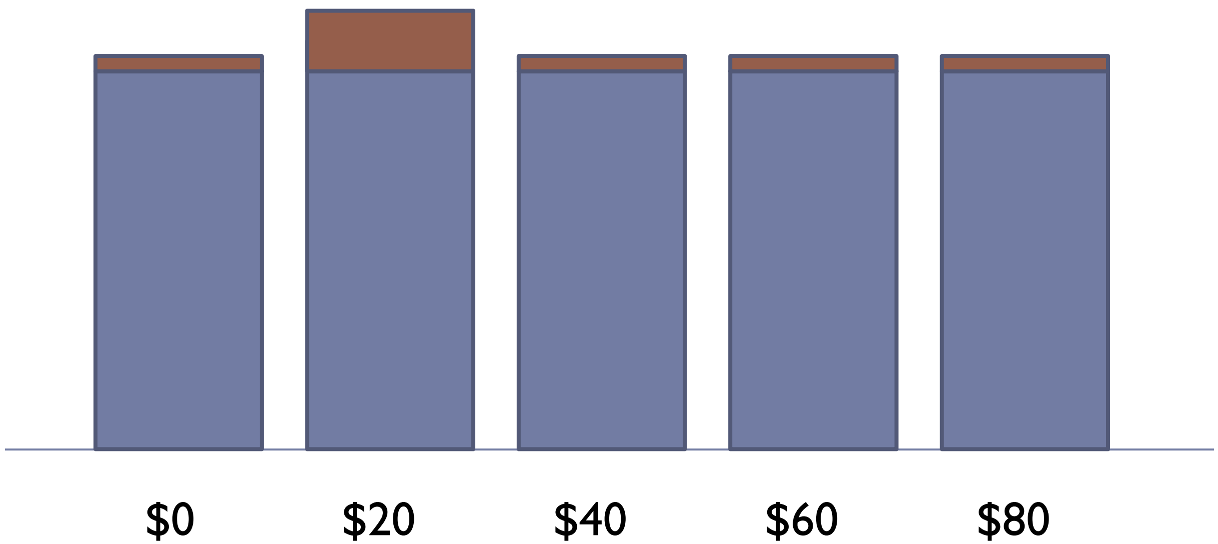
Erev-Roth Algorithm

- First all propensities are reduced by a factor 1 - r



Erev-Roth Algorithm

- Now the profit is added on. However, it doesn't all go to action '$20'. (1- e)% goes to action '$20', and the rest is evenly distributed amongst the other actions (e/(K-1)%)



Agent-Based Modelling

- Erev-Roth is commonly used in the academic literature
  - Nicolaisen et al. (2001), Testfatsion et al. (2004 onwards), Micola et al. (2006), Weidlich (2008)
- Greedy Algorithms
  - Bower and Bunn (2000)
- Belief-Based Algorithms
  - Best response, fictitious play, EWA (don't perform well)
- Genetic Algorithms
  - Nicolaisen et al. (2000)

Agent-Based Modelling

- Several large-scale agent-based models have been developed based upon various algorithms
  - EMCAS (Argonne National Laboratory)
  - Marketecture (Los Alamos National Laboratory)
    - Greedy algorithm
  - N-ABLE (Sandia National Laboratory)
    - Genetic algorithm
  - STEMS (Electric Power Research Institute)
    - Greedy algorithm?
  - NEMSIM (CSIRO, Australia)
    - Bids based upon historical behaviour?

SWEM: Agent Modelling of the NZEM

- Goal is to create a model that can test policy options in the current New Zealand wholesale market
  - Will an asset swap lower prices?
  - Who benefits from transmission line upgrades?

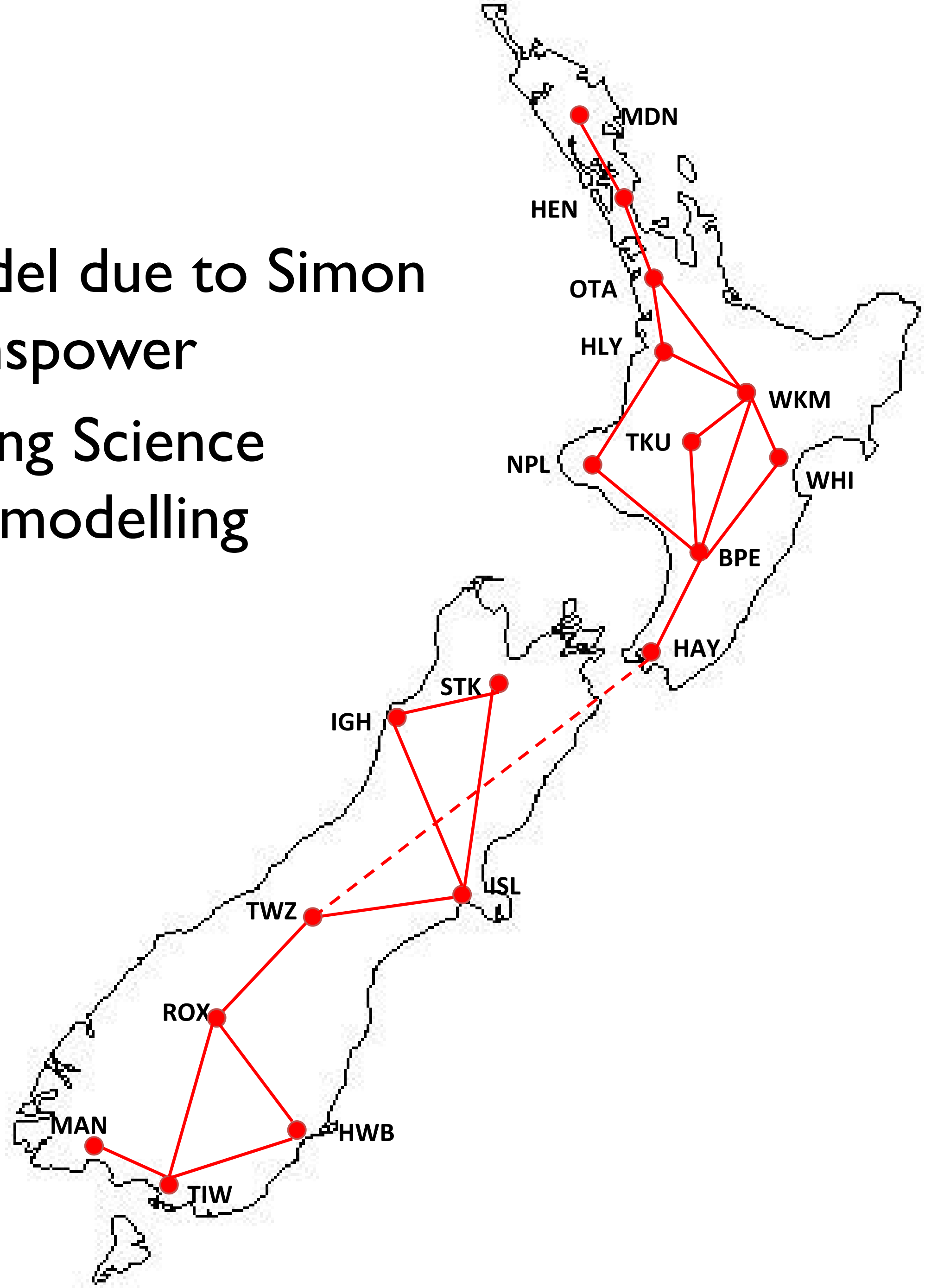
- Implies I need a model that can realistically predict nodal prices in the New Zealand market
- SWEM is the agent-based model I am developing for this purpose

SWEM: Algorithm

- I have selected the modified Erev-Roth algorithm modified to allow for firms owning multiple generators
  1. Generator bids depend only upon profit.
     - Algorithm should behave consistently across different networks and market setups
  2. Well documented in the literature
     - Several published papers justify the use of this algorithm and many examples of use in electricity bidding
  3. Compares well to human players and gets close to Nash equilibria (+/- some randomness)

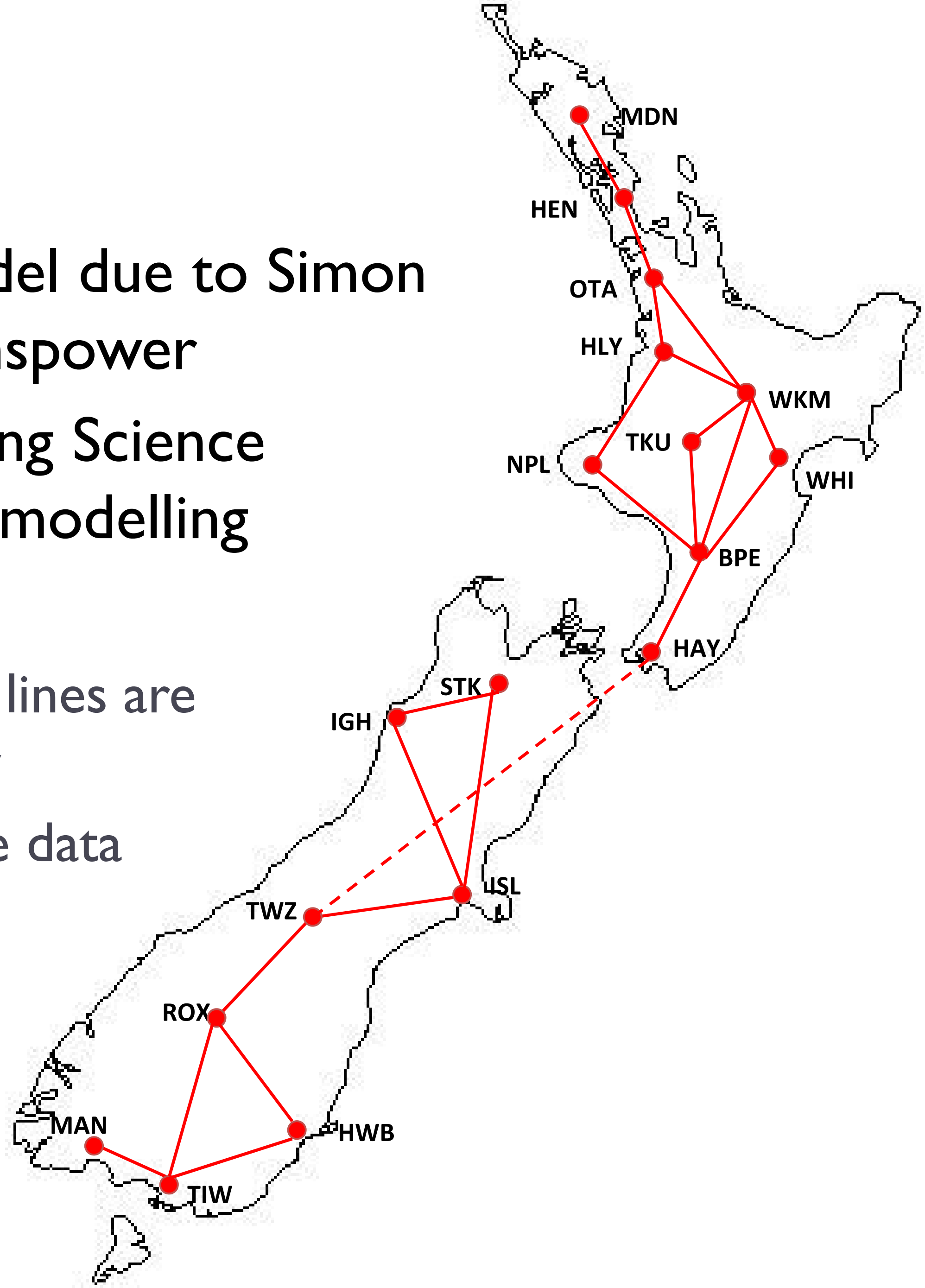
SWEM: Data

- Starting point is a model due to Simon Young (1998) and Transpower
- Used by the Engineering Science Department for their modelling



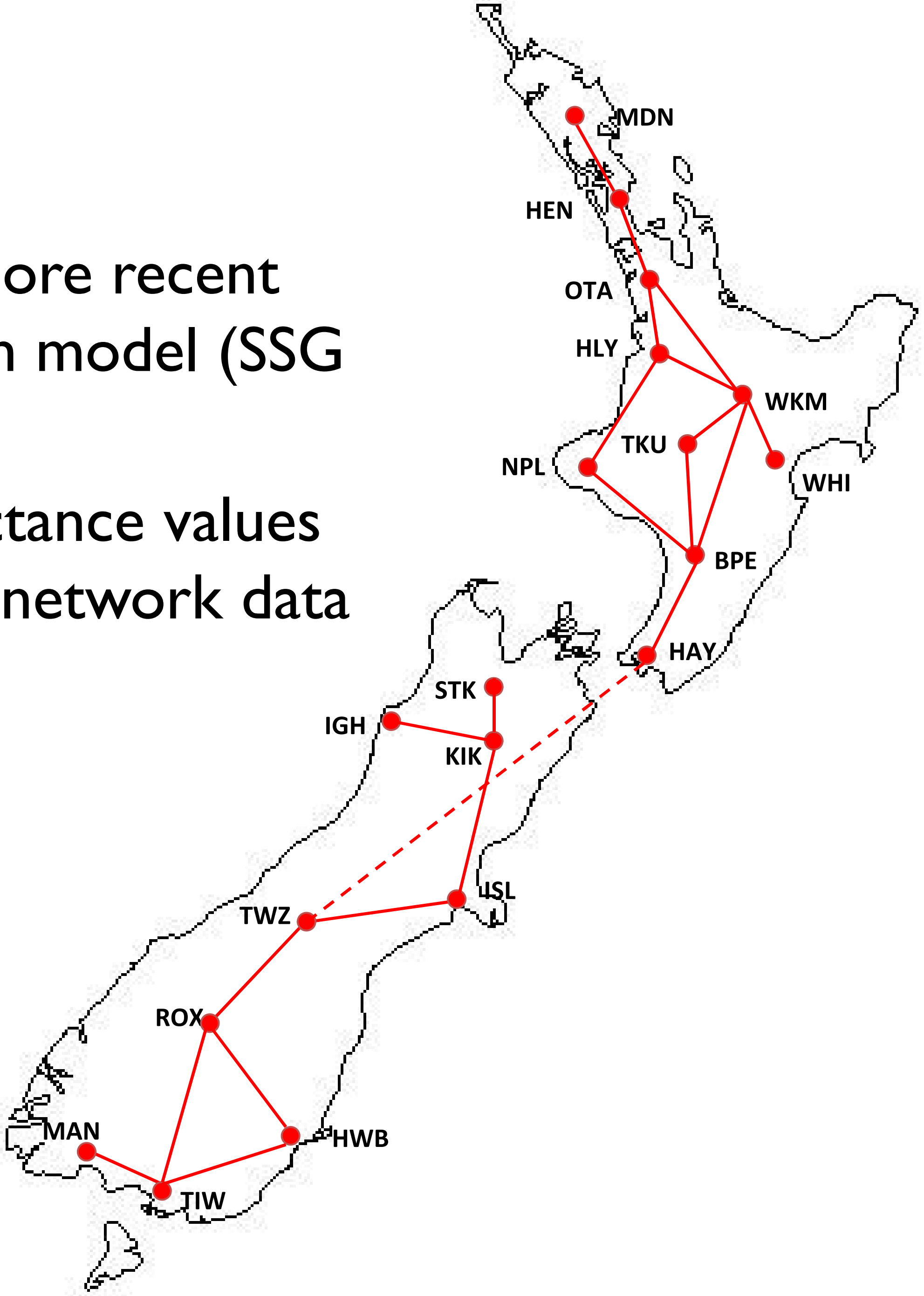
SWEM: Data

- Starting point is a model due to Simon Young (1998) and Transpower
- Used by the Engineering Science Department for their modelling
- Issues
  - IGH-ISL and WHI-BPE lines are operationally split now
  - Capacity and reactance data from 1998



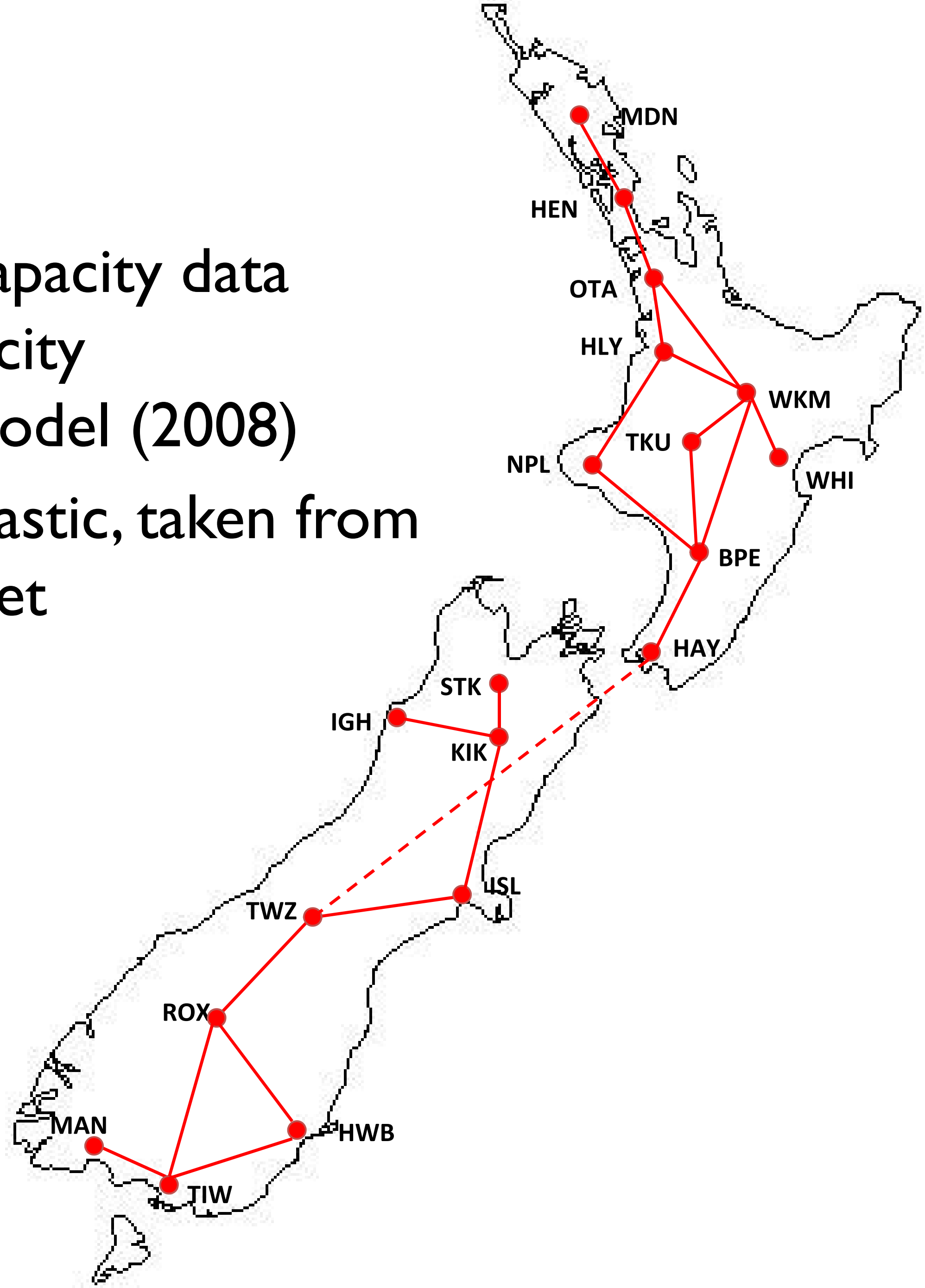
SWEM: Data

- I merged this with a more recent Electricity Commission model (SSG 2006)
- Uses capacity and reactance values aggregated from 2006 network data



SWEM: Data

- Generator cost and capacity data taken from the Electricity Commission's GEM model (2008)
- Demand assumed inelastic, taken from the Centralized Dataset



SWEM: Data

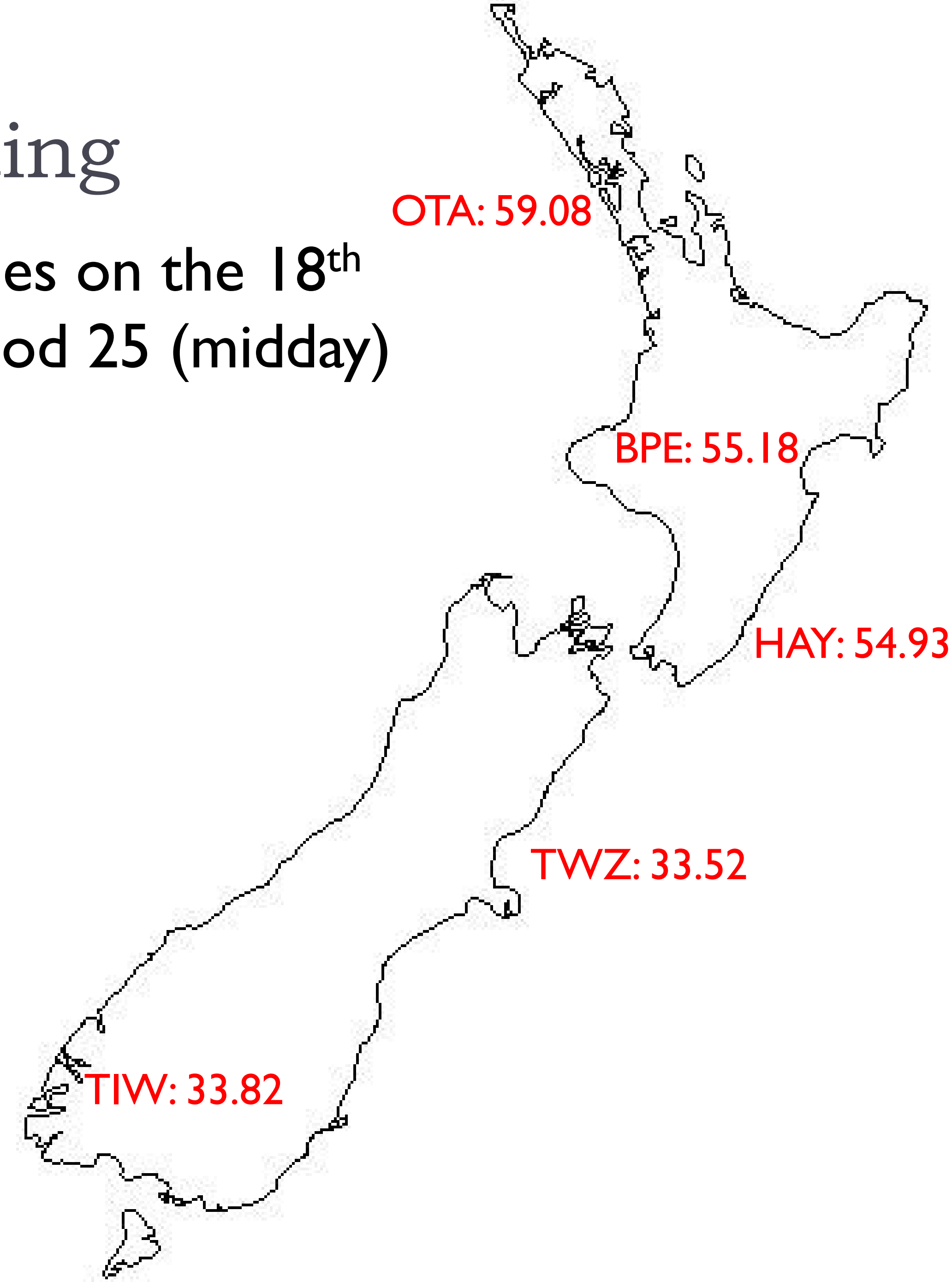
- Validating the choice of simplified network is potentially important, since bad data can skew results
- One option is to take historical bids, run them through each model, and compare the nodal prices in each model to the real prices
  - Approach used by Alex John (Engineering Science Hons Student)
- Alternatively, David Hume (Electricity Commission) suggests comparing total line flows in the models versus the real network as a means of comparison

SWEM: Calibrating

- Current model parameters are
  - r = 0.06, e = 0.98, n = 1500, Ψ = 0.7
  - These were chosen simply by 'visual comparison' of model prices with the real prices on 14th January 2010, and are similar to those used by other authors
  - A model price is calculated by 10 repeated runs with a different random seed and then averaged
- I'm currently working on a more sophisticated calibration exercise using 96 periods across 2009
  - Need a metric to compare SWEM's predictions against real world prices
  - Be sure to correct for real world supply-side interruptions

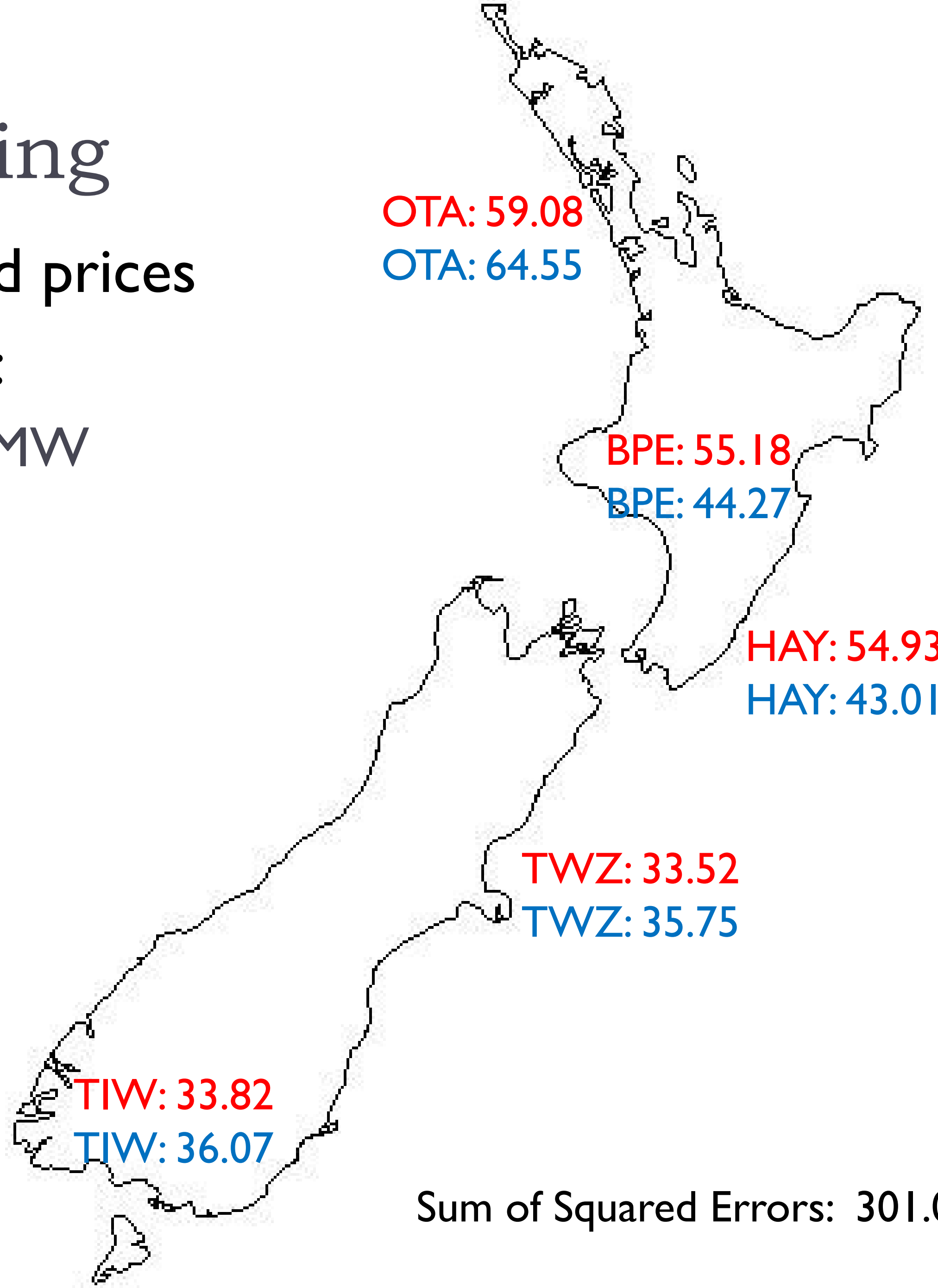
SWEM: Calibrating

- Here are the real prices on the 18th February 2009 at period 25 (midday)



SWEM: Calibrating

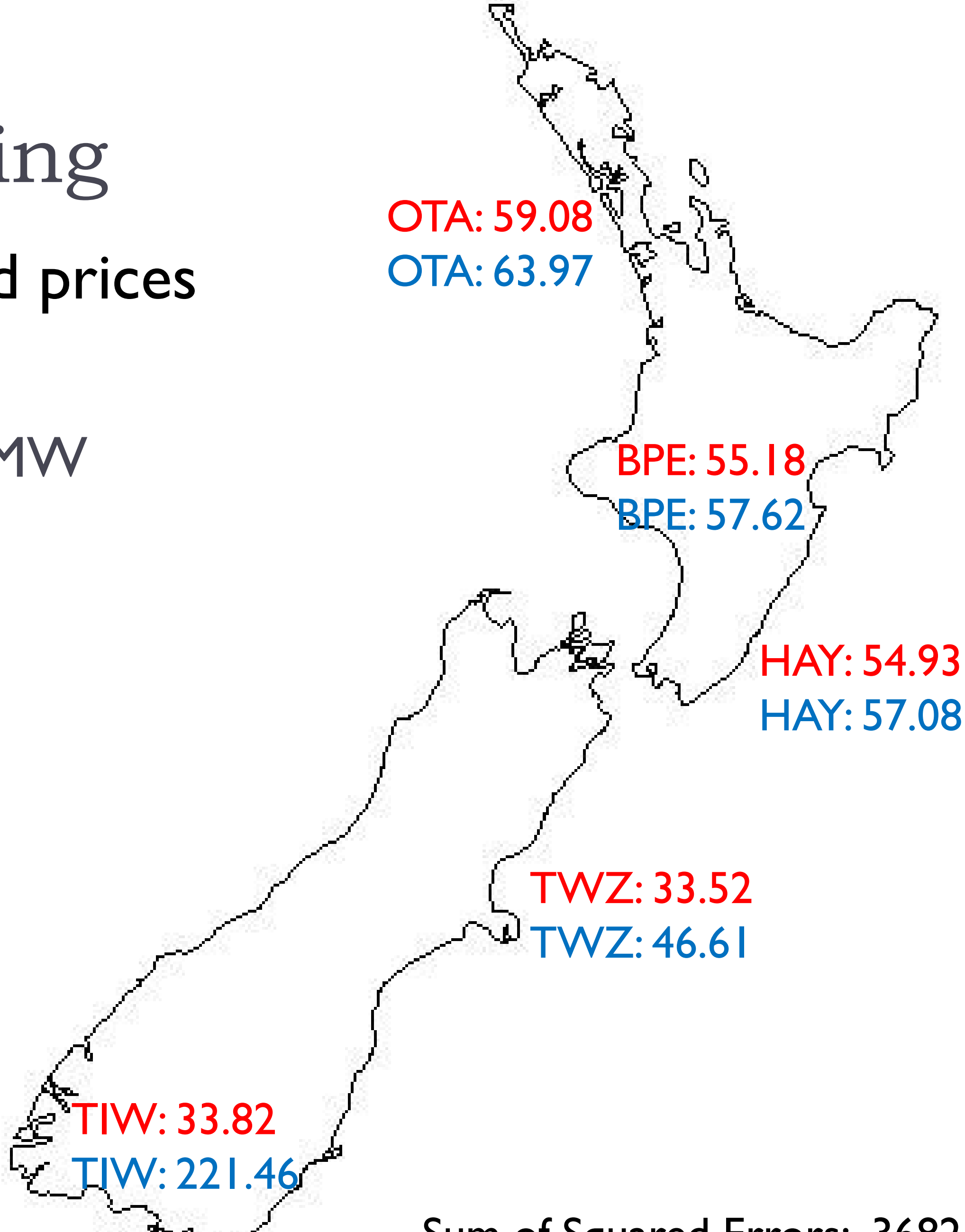
- Here are the simulated prices in period 25 assuming:
  - HVDC capacity is 700MW



Sum of Squared Errors: 301.07

SWEM: Calibrating

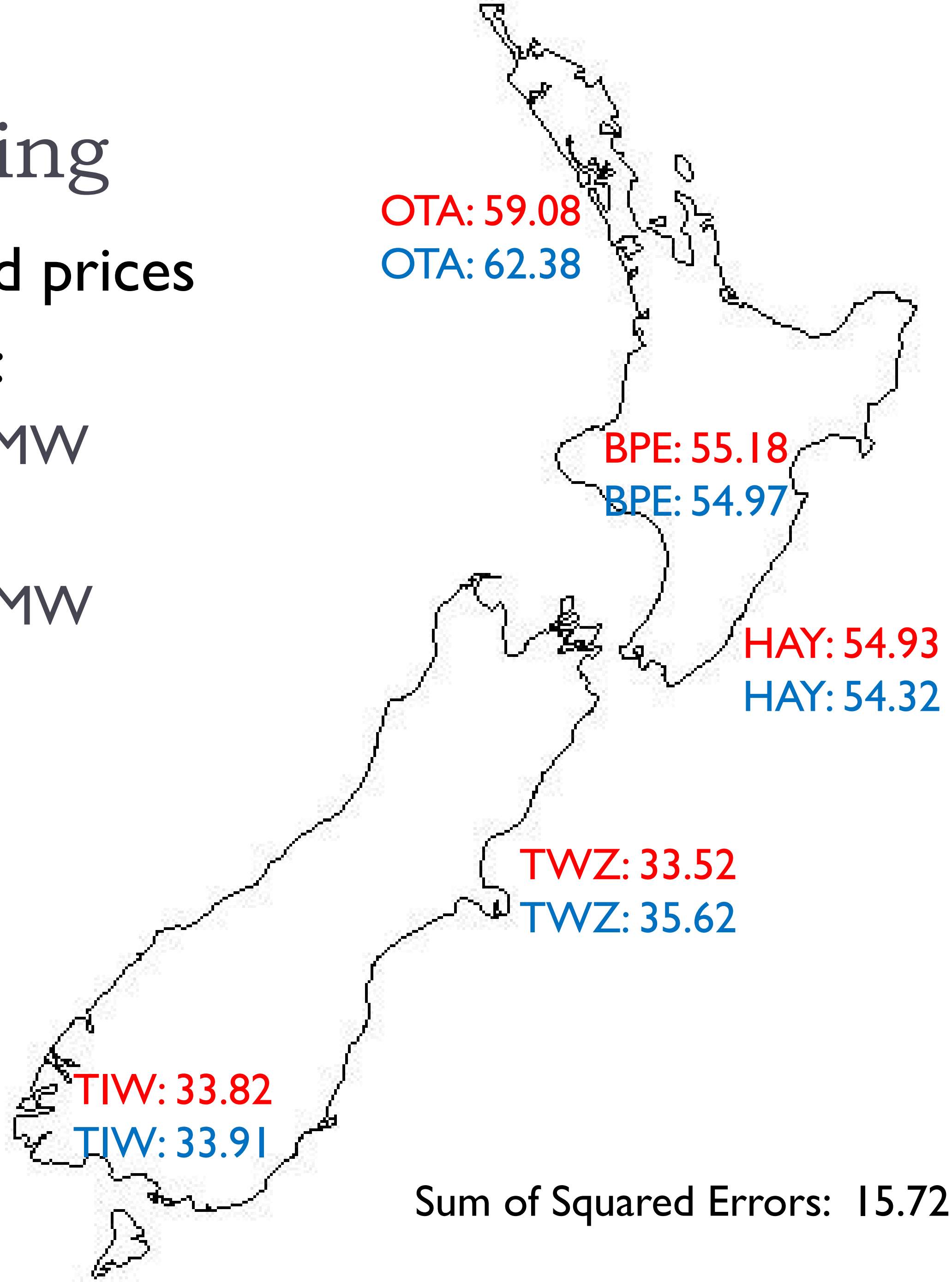
- Here are the simulated prices in period 25 assuming:
  - HVDC capacity is 700MW
  - No wind is blowing



Sum of Squared Errors: 36824.49

SWEM: Calibrating

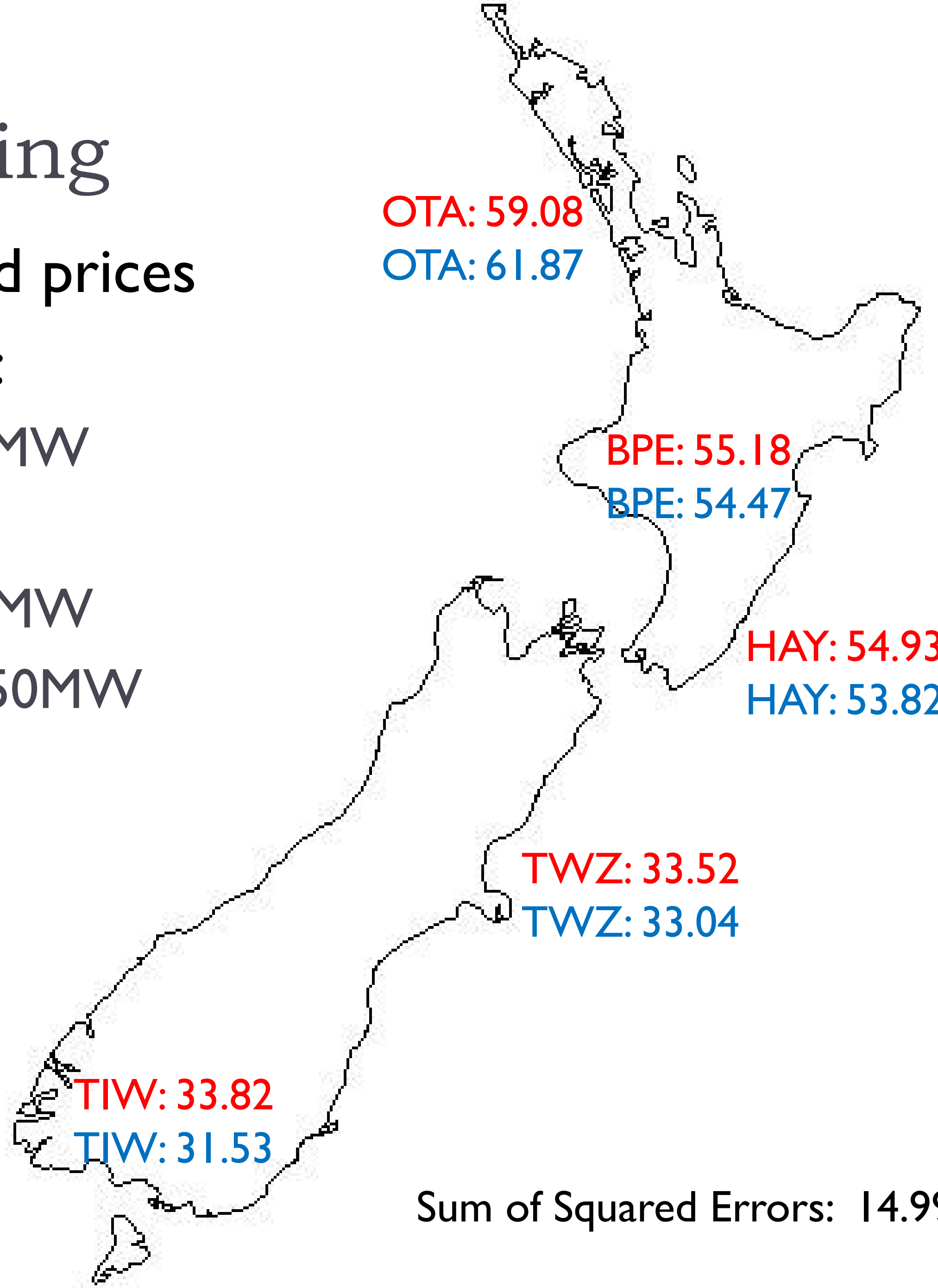
- Here are the simulated prices in period 25 assuming:
  - HVDC capacity is 700MW
  - No wind is blowing
  - Tiwai Contract of 572MW



Sum of Squared Errors: 15.72

SWEM: Calibrating

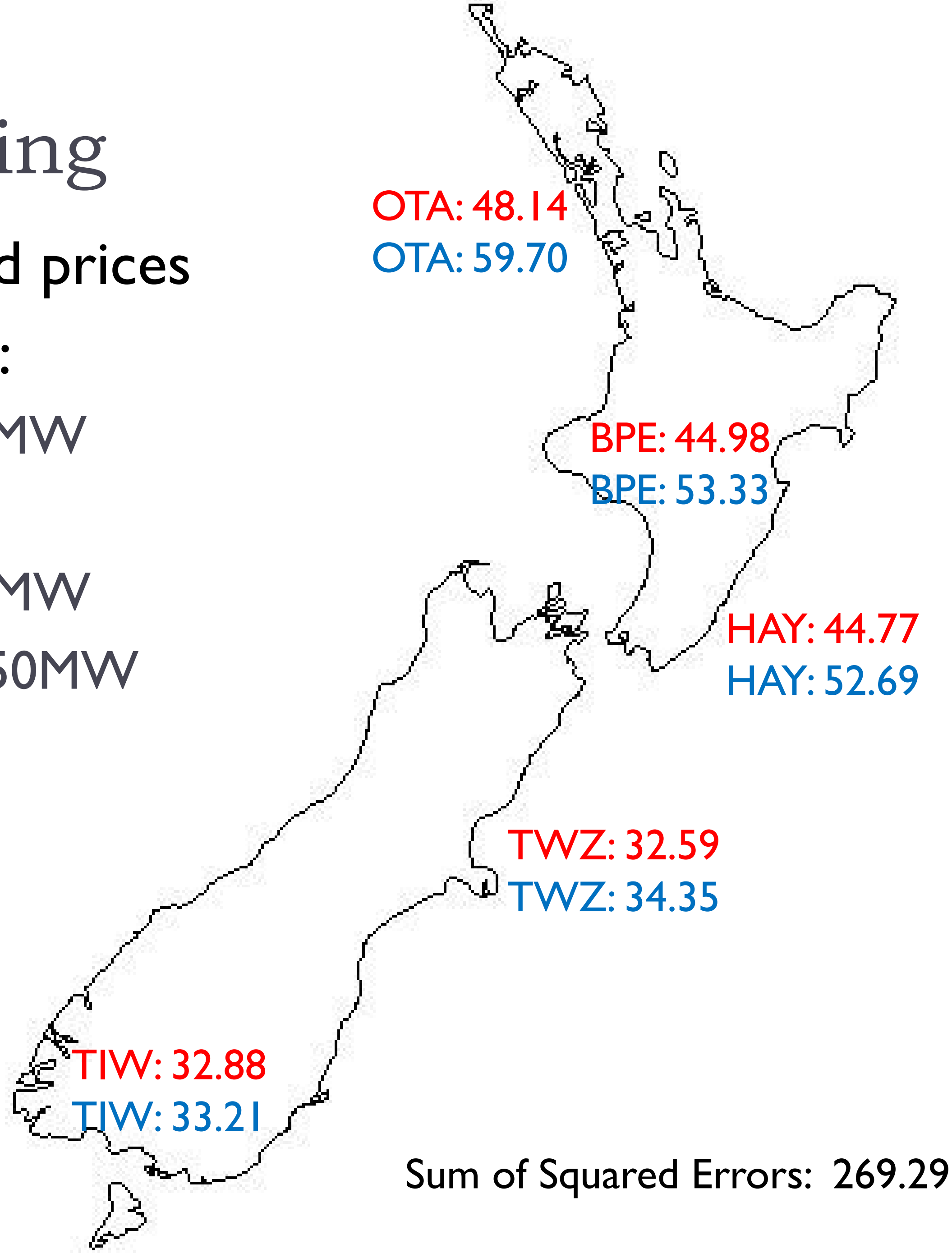
- Here are the simulated prices in period 25 assuming:
  - HVDC capacity is 700MW
  - No wind is blowing
  - Tiwai Contract of 572MW
  - Benmore capacity is 450MW



Sum of Squared Errors: 14.99

SWEM: Calibrating

- Here are the simulated prices in period **24** assuming:
  - HVDC capacity is 700MW
  - No wind is blowing
  - Tiwai Contract of 572MW
  - Benmore capacity is 450MW



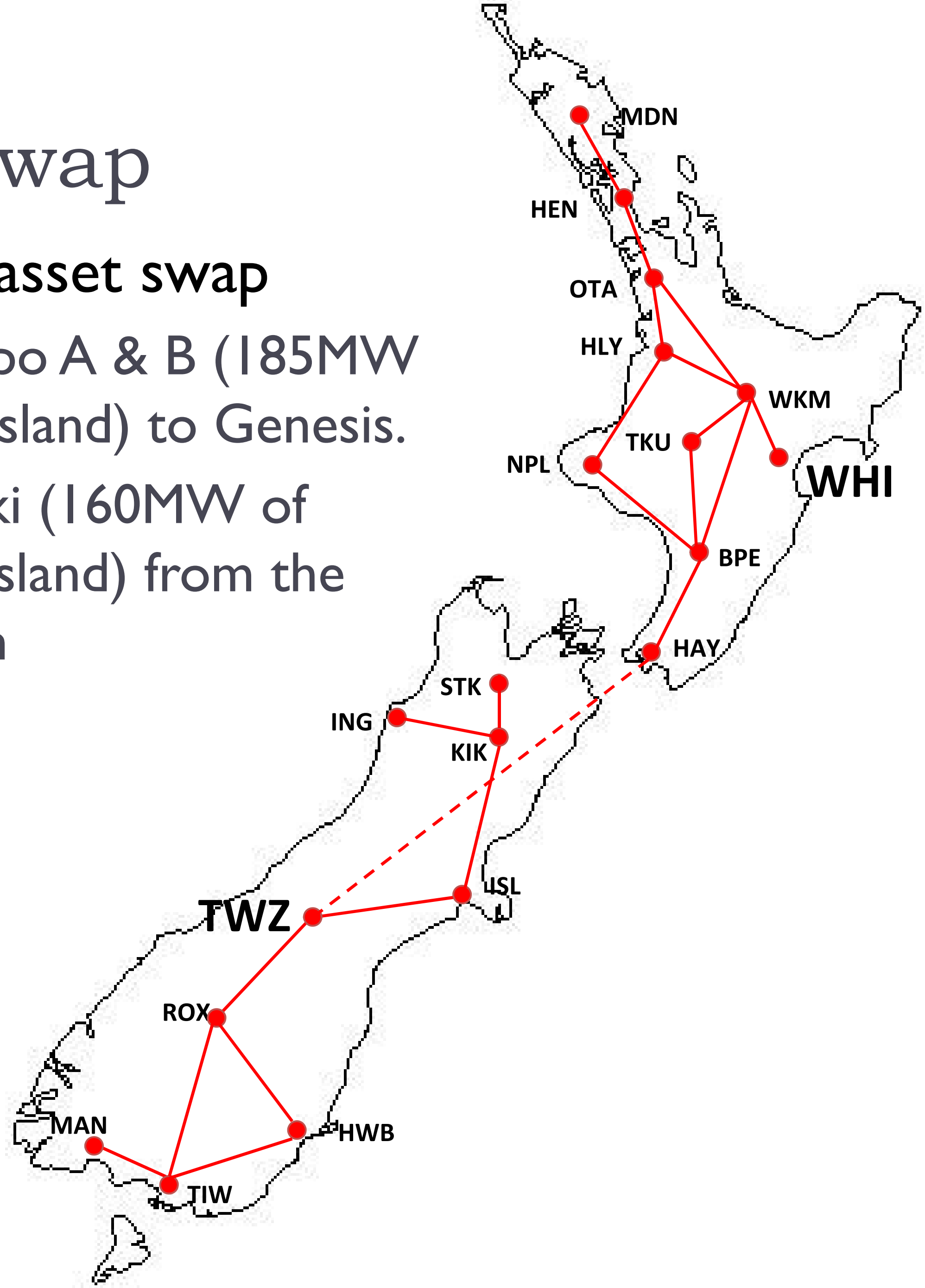
SWEM: Calibrating

- Running times
  - In the 19 node model, a simulation of prices in one half hour period takes ~790 seconds (13 minutes)
  - During this time, the program solves the market clearing problem 15000 times. This gives 10 different predictions, which are then averaged to get the final prediction
  - Code not yet optimized for speed, though

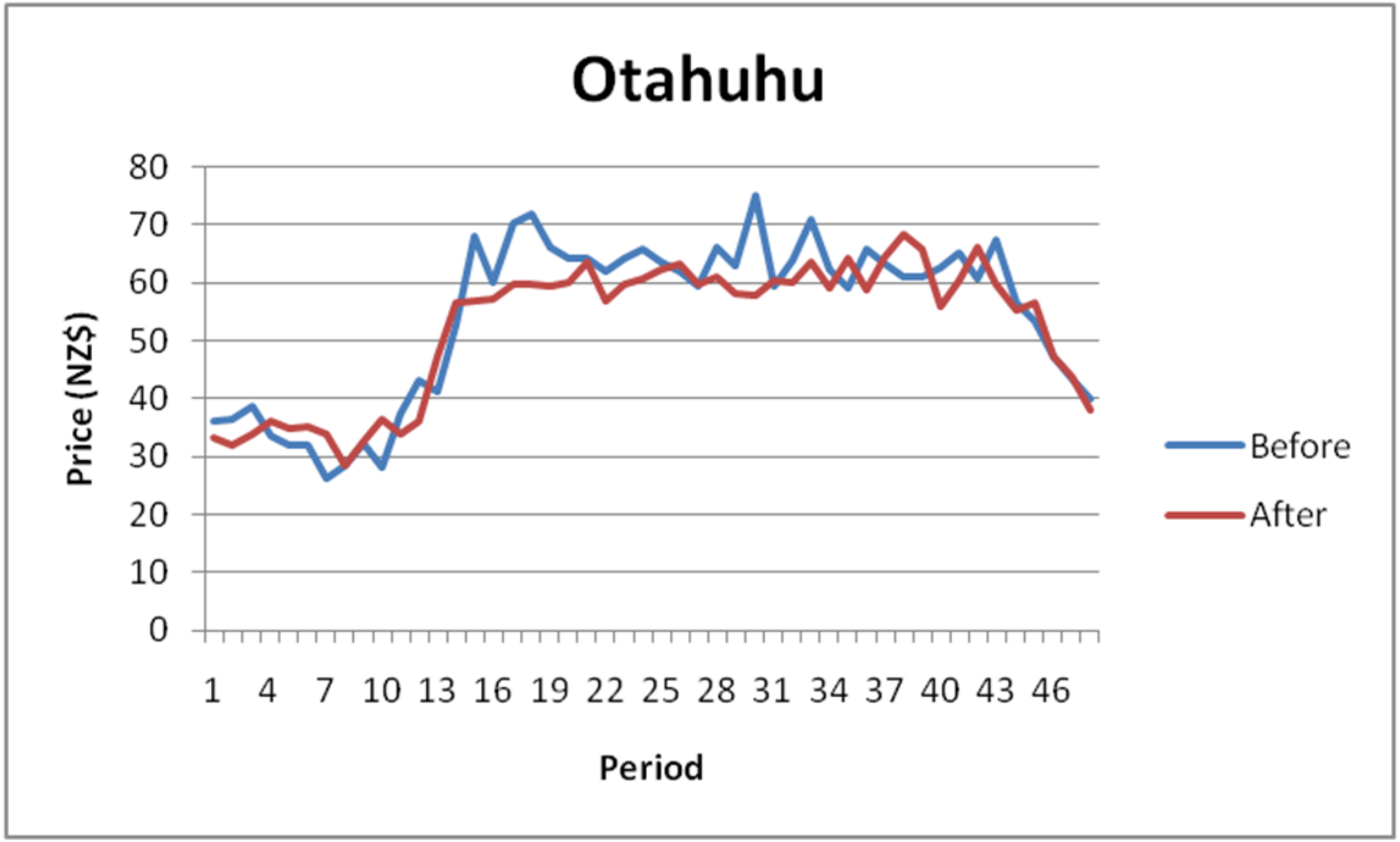
- There are 'smarter' refinements of the basic algorithm in the published literature which I have yet to test

Results: Asset Swap

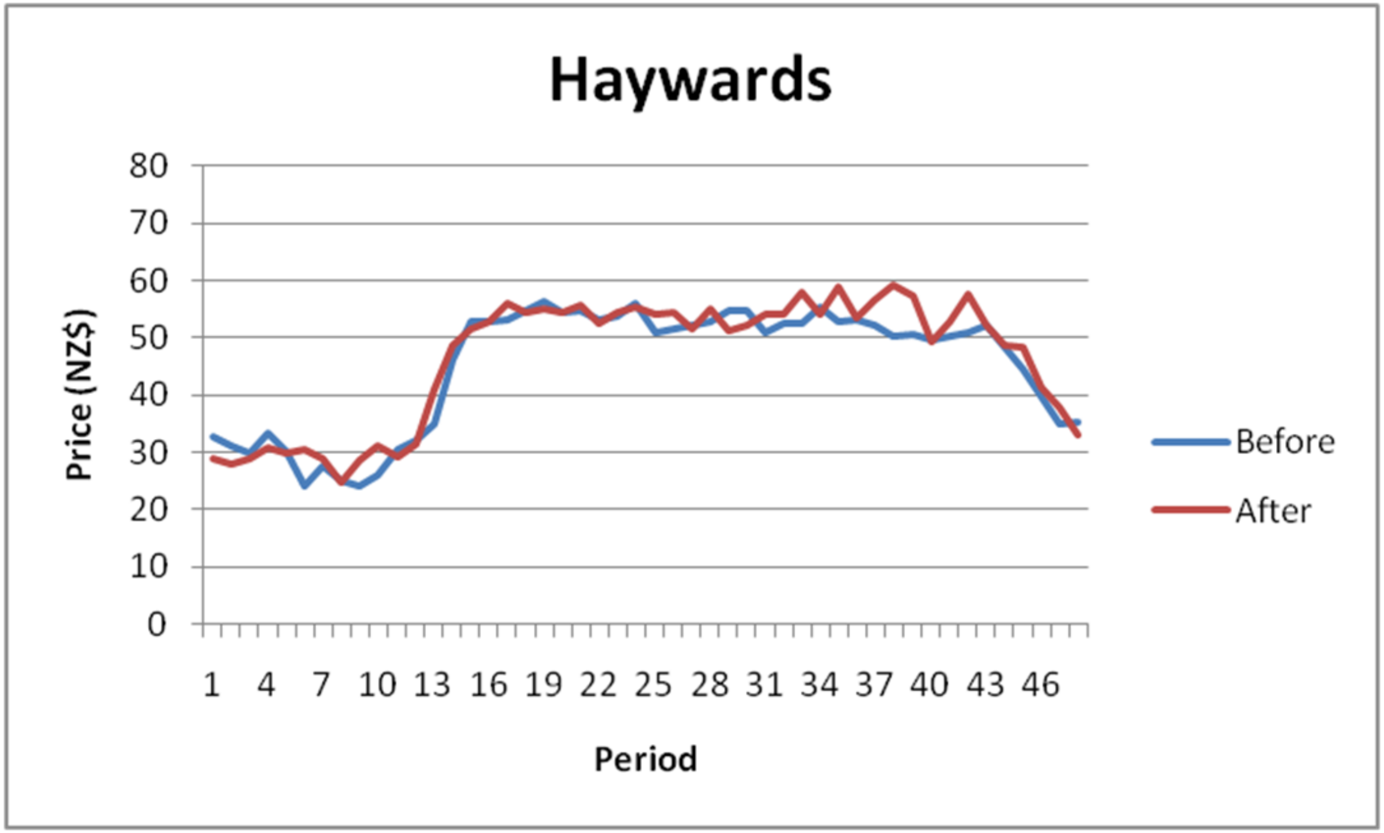
- I model the following asset swap
  - Meridian gives up Tekapo A & B (185MW of hydro in the South Island) to Genesis.
  - Meridian gets Whirinaki (160MW of thermal in the North Island) from the Electricity Commission



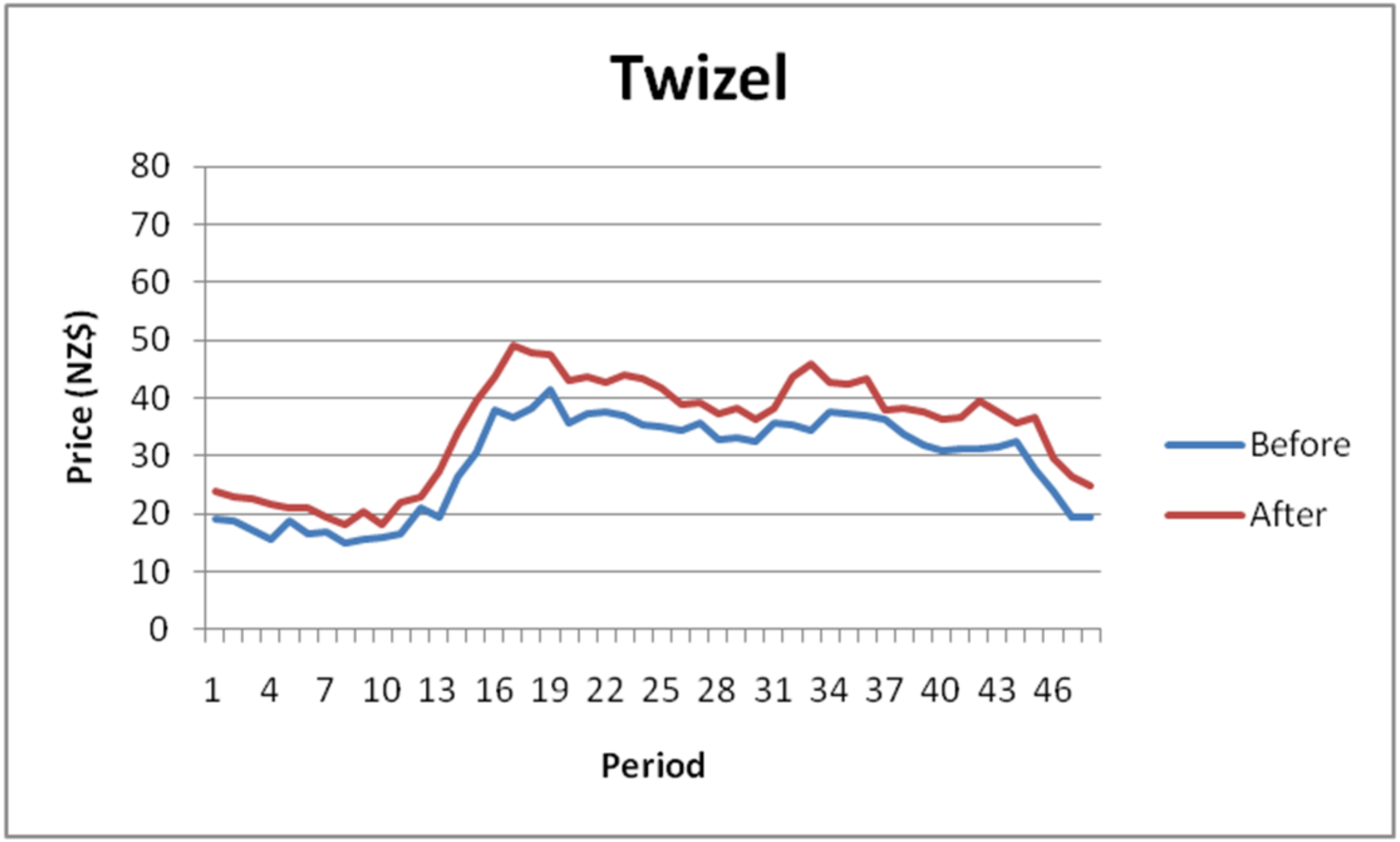
Results: Asset Swap



Results: Asset Swap



Results: Asset Swap



Results: Asset Swap

- The HVDC is more less frequently congested after the asset swap, and this causes prices in the South Island to rise (on average)
- NI prices do not change much

Results: Asset Swap

- Bidding Analysis for a sample period (period 22)

Average Bids	Before Swap	After Swap
Tekapo A (25MW)	$132	$182
Tekapo B (160MW)	$27	$115
Whirinaki	$300	$468
Huntly Units 1 & 2	$202/$170	$71/$57
Huntly Units 3 & 4	$165/$153	$165/$154
E3P	$76	$83
AVI/BEN/WTK	$60/$57/$52	$79/$39/$57
Manapouri	$46	$109

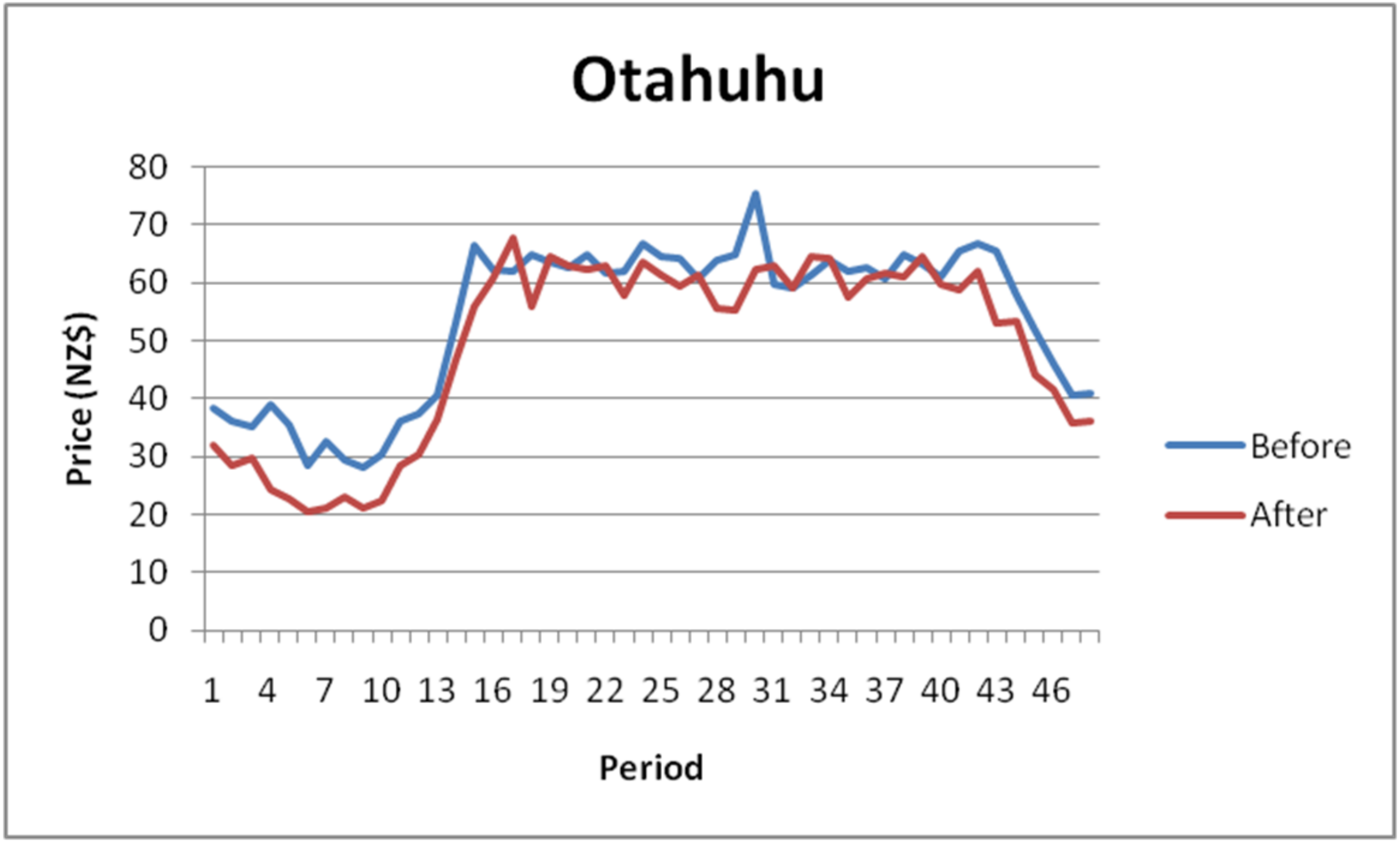
Results: Asset Swap

- In practice, Genesis would never run Tekapo at 0
  - Minimum river flows
  - Political outcry if spilling water
- The lack of minimum flows and other must-run generation also impacts SWEM's predictions of off-peak prices – SWEM's off-peak predictions are consistently higher than real prices
- Conclusion: Incorporate must-run constraints into the model

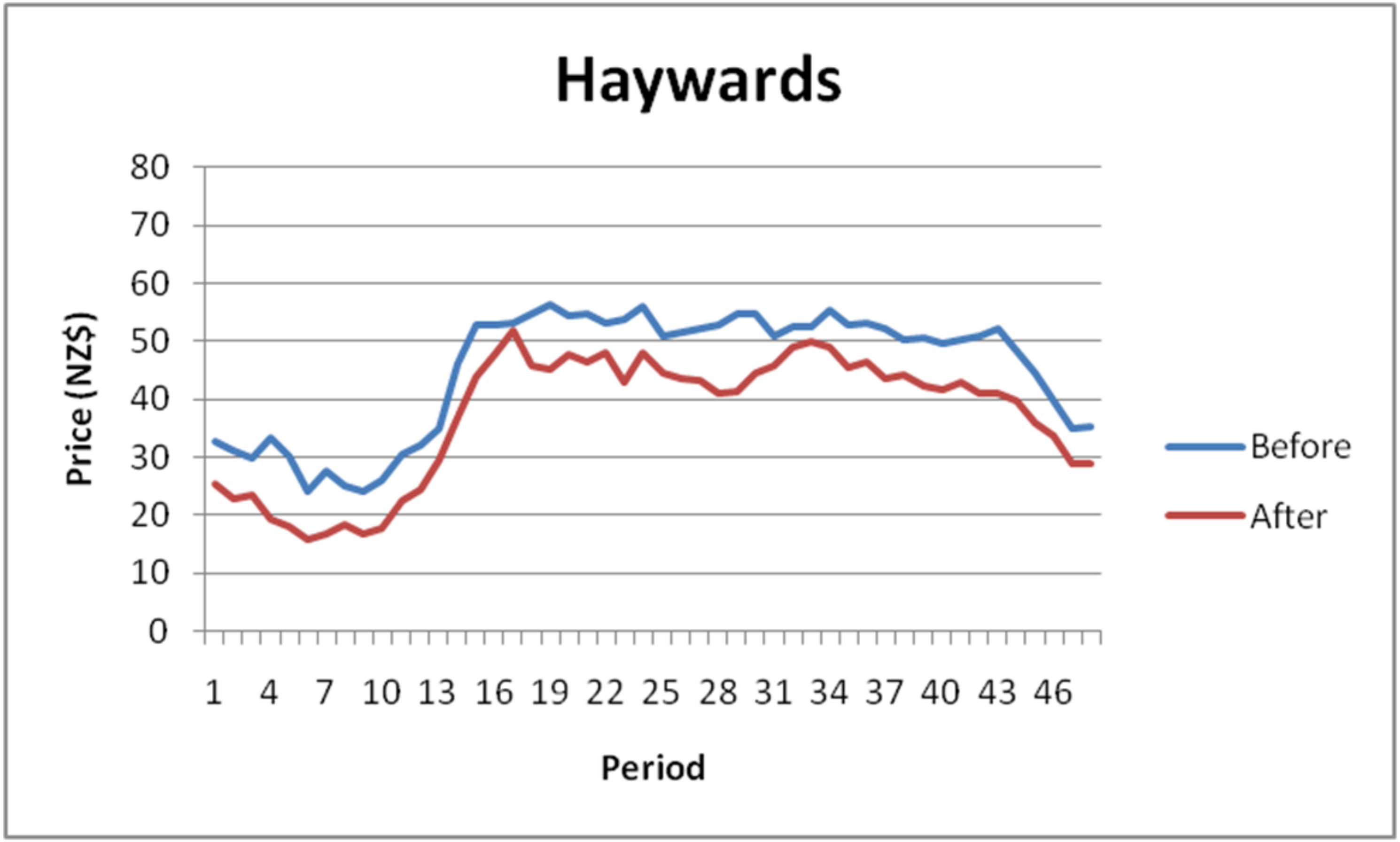
Results: HVDC Upgrade

Average Firm Wholesale Profits for a Half Hour Trading Period						
HVDC Capacity	**Meridian**	**Genesis**	**Contact**	**MRP**	**Trustpower**	**Todd**
700MW	18912.19	15981.46	19414.00	25028.87	8868.48	1328.42
1200MW	25260.95	12362.38	19736.77	19379.84	8637.10	959.88
% Change	33.57%	-22.65%	1.66%	-22.57%	-2.61%	-27.74%

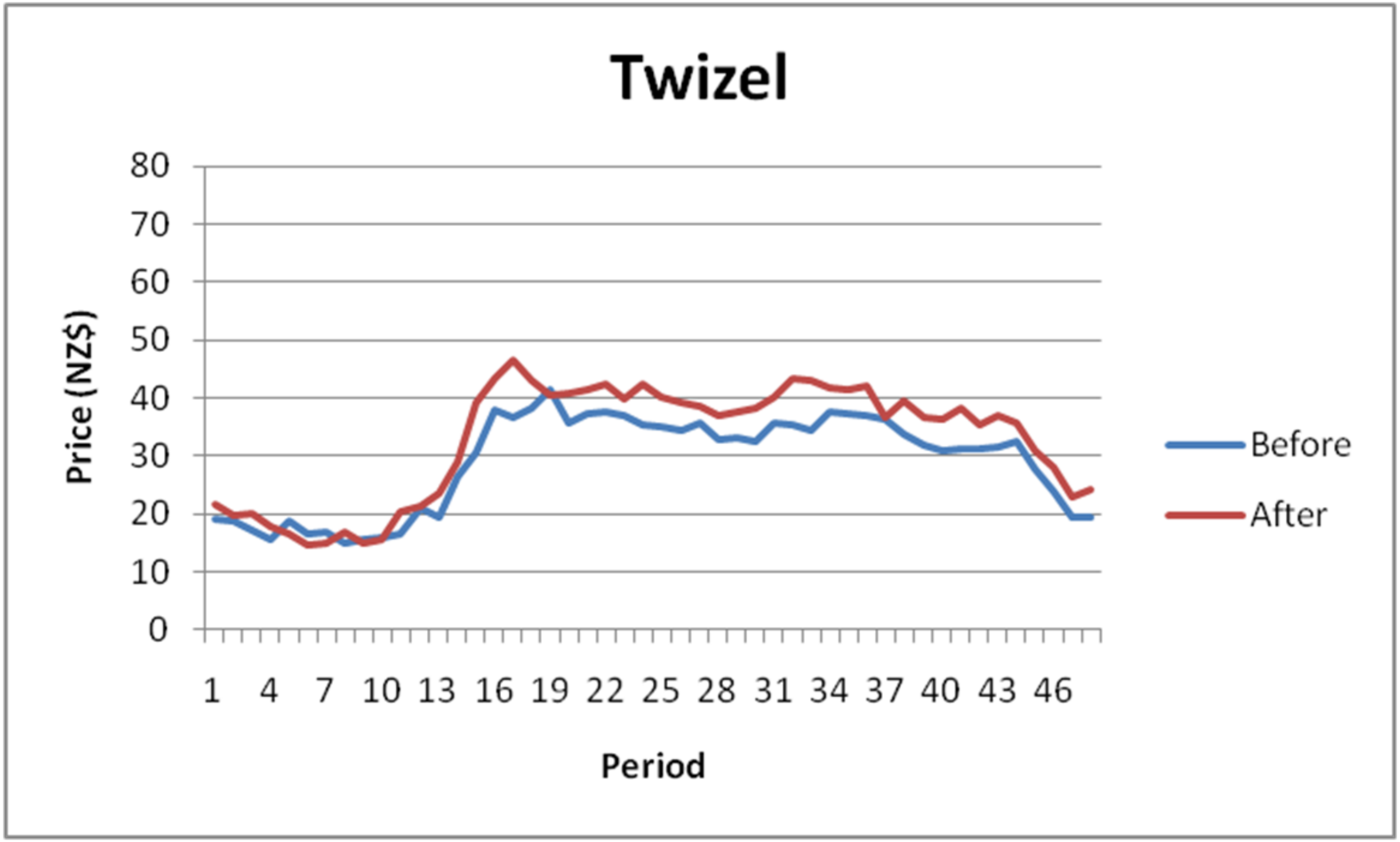
Results: HVDC Upgrade



Results: HVDC Upgrade



Results: HVDC Upgrade



Where to from here?

- No reserves market or frequency keeping generators
  - Could add this with some work, several multi-market agent-based models in the literature
- No retail contracts
  - Easy to add if data available
- No minimum generation requirements (such as take-or-pay contracts, minimum river flows etc)
  - Important to add these to the model
- No hydrology information such as lake levels, river flows