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.
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 $1 - r$
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 \(\left(\frac{e}{(K-1)}\right)\%\).
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
  - \( r = 0.06, e = 0.98, n = 1500, \Psi = 0.7 \)
  - These were chosen simply by ‘visual comparison’ of model prices with the real prices on 14\textsuperscript{th} 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)
  - OTA: 59.08
  - BPE: 55.18
  - HAY: 54.93
  - TWZ: 33.52
  - TIW: 33.82
SWEM: Calibrating

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

OTA: 59.08
OTA: 64.55
BPE: 55.18
BPE: 44.27
HAY: 54.93
HAY: 43.01
TWZ: 33.52
TWZ: 35.75
TIW: 33.82
TIW: 36.07

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

OTA: 59.08
OTA: 63.97
BPE: 55.18
BPE: 57.62
HAY: 54.93
HAY: 57.08
TWZ: 33.52
TWZ: 46.61
TIW: 33.82
TIW: 221.46

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

OTA: 59.08
OTA: 62.38
BPE: 55.18
BPE: 54.97
HAY: 54.93
HAY: 54.32
TWZ: 33.52
TWZ: 35.62
TIW: 33.82
TIW: 33.91

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

OTA: 59.08
OTA: 61.87
BPE: 55.18
BPE: 54.47
HAY: 54.93
HAY: 53.82
TWZ: 33.52
TWZ: 33.04
TIW: 33.82
TIW: 31.53

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

OTA: 48.14
OTA: 59.70
BPE: 44.98
BPE: 53.33
HAY: 44.77
HAY: 52.69
TWZ: 32.59
TWZ: 34.35
TIW: 32.88
TIW: 33.21

Sum of Squared Errors: 269.29
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)

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

<table>
<thead>
<tr>
<th>HVDC Capacity</th>
<th>Meridian</th>
<th>Genesis</th>
<th>Contact</th>
<th>MRP</th>
<th>Trustpower</th>
<th>Todd</th>
</tr>
</thead>
<tbody>
<tr>
<td>700MW</td>
<td>18912.19</td>
<td>15981.46</td>
<td>19414.00</td>
<td>25028.87</td>
<td>8868.48</td>
<td>1328.42</td>
</tr>
<tr>
<td>1200MW</td>
<td>25260.95</td>
<td>12362.38</td>
<td>19736.77</td>
<td>19379.84</td>
<td>8637.10</td>
<td>959.88</td>
</tr>
<tr>
<td>% Change</td>
<td>33.57%</td>
<td>-22.65%</td>
<td>1.66%</td>
<td>-22.57%</td>
<td>-2.61%</td>
<td>-27.74%</td>
</tr>
</tbody>
</table>
Results: HVDC Upgrade

![Graph showing price changes over periods before and after HVDC upgrade in Otahuhu.](image)

Price (NZ$) vs. Period (1 to 46)

- Blue line: Before
- Red line: After
Results: HVDC Upgrade
Results: HVDC Upgrade

![Graph showing price changes over periods before and after HVDC upgrade in Twizel.](image)
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