Climate and the NZ Electricity Spot Market

Lewis Evans
NZ Institute for the Study of Competition and Regulation
Victoria University of Wellington

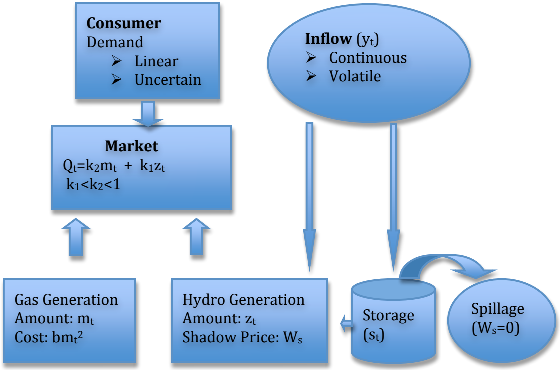
March 21 2012
Presentation at the Motu Climate Economics Workshop
Draws on work of Lewis Evans, Graeme Guthrie, Andrea Lu and John Nash

Outline

1. The Electricity Market
2. Decision making with uncertain demand and inflows
3. The Base case
4. Outcomes of competition and monopoly
5. Effects of changes in climate (inflows/carbon tax)
6. Possibilities

The Spot Market

The Market



New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

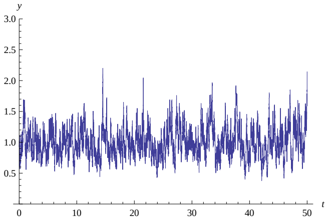
- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

New Zealand Electricity Market Calibration 2007

- Quantity: q is TWh
- Demand curve: $P(q) = 185 - 3.47q$ [plus price shocks for a given quantity]
  elasticity of demand $= 0.4$ (Borenstein and Bushnell, 1998)
- $k_1 = 0.956$ (Otahuhu-Benmore)
  $k_2 = 0.984$ (Otahuhu-Hayward)
- Generation Capacity $\bar{z} = 47$ and $\bar{m} = 35$ TWh/y
- Lake Capacity $\bar{s} = 4.44$ TWh
- The risk-free interest rate $r = 0.04$
- Cost of gas: $C(m) = 0.7112m^2$
  - Marginal cost of generating the total quantity of non-hydro electricity generated in 2007 plus transmission costs equals the market price in 2007.

50 Years of Daily Inflows

- stationary diffusion process: with mean = 1
- increment in inflow =mean reversion*(1-inflow) + shock (affected by variance and inflow level)
- $dy_t = 6.9448(1 - y_t)dt + 0.9056\sqrt{y_t}d\epsilon_t$



Social Planner Objectives I

- Given m_t and z_t, the flow of net social benefit at date t is

  $NSB(z_t, m_t, y_t) = Area\ under\ demand\ curve\ less\ cost\ of\ gas\ generation$

- No other use for water and reservoir fixed cost, so no water cost in flow of net social benefit
- Social planner's ultimate interest is in maximizing the *expected present value* of net social benefit
- $$W(s, y) = E_0\left[\int_0^\infty e^{-rt} NSB(z_t, m_t) dt\right]$$

Social Planner Objectives I

- Given m_t and z_t, the flow of net social benefit at date t is

  $NSB(z_t, m_t, y_t) = \textit{Area under demand curve less cost of gas generation}$

- No other use for water and reservoir fixed cost, so no water cost in flow of net social benefit
- Social planner's ultimate interest is in maximizing the *expected present value* of net social benefit
- $$W(s, y) = E_0 \left[\int_0^\infty e^{-rt} NSB(z_t, m_t) dt \right]$$

Social Planner Objectives I

- Given m_t and z_t, the flow of net social benefit at date t is

  $NSB(z_t, m_t, y_t) = \textit{Area under demand curve less cost of gas generation}$

- No other use for water and reservoir fixed cost, so no water cost in flow of net social benefit
- Social planner's ultimate interest is in maximizing the *expected present value* of net social benefit
- $$W(s, y) = E_0 \left[\int_0^\infty e^{-rt} NSB(z_t, m_t) dt \right]$$

Social Planner Objectives II

Intertemporal equilibrium

- <1-> Given generation policy (m, z), total welfare W must satisfy

$$\underbrace{rW}_{\text{``required return''}} = \underbrace{\underbrace{NSB(m,z,y)}_{\text{Net Social Benefit}} + \underbrace{(y-z)\frac{\partial W}{\partial s} + \nu\frac{\partial W}{\partial y} + \frac{1}{2}\phi^2\frac{\partial^2 W}{\partial y^2}}_{\text{expected social ``capital gain''}}}_{\text{expected ``total return''}}$$

- The value of marginal unit of stored water , $\frac{\partial W}{\partial s}$, appears as an element of expected social capital gain.
- Planner chooses generation (m, z) to maximize RHS of required return : that is, maximise the social planner's "short-run" objective function

$$NSB(m,z,y) - cost of water = area under demand curve - \underbrace{c(m) - z\frac{\partial W}{\partial s}}_{\text{generation cost:}}$$

Social Planner Objectives II

Intertemporal equilibrium

- <1-> Given generation policy (m, z), total welfare W must satisfy

$$\underbrace{rW}_{\text{"required return"}} = \underbrace{\underbrace{NSB(m,z,y)}_{\text{Net Social Benefit}} + \underbrace{(y-z)\frac{\partial W}{\partial s} + \nu \frac{\partial W}{\partial y} + \frac{1}{2}\phi^2 \frac{\partial^2 W}{\partial y^2}}_{\text{expected social "capital gain"}}}_{\text{expected "total return"}}$$

- The value of marginal unit of stored water , $\frac{\partial W}{\partial s}$, appears as an element of expected social capital gain.
- Planner chooses generation (m, z) to maximize RHS of required return : that is, maximise the social planner's "short-run" objective function

$$NSB(m,z,y) - cost of water = area under demand curve - \underbrace{c(m) - z\frac{\partial W}{\partial s}}_{\text{generation cost:}}$$

Social Planner Objectives II

Intertemporal equilibrium

- <1-> Given generation policy (m, z), total welfare W must satisfy

$$\underbrace{rW}_{\text{"required return"}} = \underbrace{\underbrace{NSB(m,z,y)}_{\text{Net Social Benefit}} + \underbrace{(y-z)\frac{\partial W}{\partial s} + \nu\frac{\partial W}{\partial y} + \frac{1}{2}\phi^2\frac{\partial^2 W}{\partial y^2}}_{\text{expected social "capital gain"}}}_{\text{expected "total return"}}$$

- The value of marginal unit of stored water , $\frac{\partial W}{\partial s}$, appears as an element of expected social capital gain.
- Planner chooses generation (m, z) to maximize RHS of required return : that is, maximise the social planner's "short-run" objective function

$$NSB(m,z,y) - cost\,of\,water = area\,under\,demand\,curve - \underbrace{c(m) - z\frac{\partial W}{\partial s}}_{\text{generation cost:}}$$

Summary:

the social planner decisions = competive market

- generation decisions are
  - static but linked to future by the shadow price of stored water
  - based upon inflows and stored fuel
  - forward looking (expectations)
  - affected by volatility in inflows and demand
- outcomes and economic welfare are affected by
  - the structure of demand and supply
    - e.g shape of demand
    - consider competition and monopoly
  - volatility in inflows and demand
  - the level and forecastability of inflows

Summary:

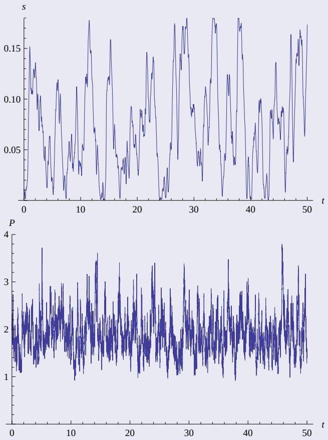
the social planner decisions = competive market

- generation decisions are
  - static but linked to future by the shadow price of stored water
  - based upon inflows and stored fuel
  - forward looking (expectations)
  - affected by volatility in inflows and demand
- outcomes and economic welfare are affected by
  - the structure of demand and supply
    - e.g shape of demand
    - consider competition and monopoly
  - volatility in inflows and demand
  - the level and forecastability of inflows

The Base Case Under Competition

Monopoly higher price, lower volatility

Storage and Price



The Base Case Under Competition

associations

Correlations

- shadow price with
  - storage: -0.83
  - inflows: -0.72
  - gas generation: 0.99
- Hydro generation with
  - storage: 0.78
  - inflows: 0.71
  - gas:-0.91
- inflow with
  - price: -0.18

Climate Change

Explore by

1. Varying mean (average) inflows
2. Varying forecastability (volatility of inflows)
3. Carbon tax

Changes in Mean Inflows

Decrease average inflow by 30%

- NIWA argues that inflow will actually increase
- Decrease in average inflow means increased amount of low-cost fuel over any reasonable period

Relative to Base	Competition	Monopoly
Hydro G	70%	71%
Gas G	1.26%	2.83%
Social W	91%	93%
Profit	1.04	96%
Social Value Extra Capacity	31%	17%
Market Value Capacity	44%	70%

Volatility spread between competition and monopoly remains

Reduced Inflow Predictability

Decrease mean reversion parameter by 30%

Increases overall variability as well

Relative to Base	Competition	Monopoly
Hydro G	100%	98%
Gas G	100%	112%
Social W	100%	100%
Profit	99%	100%
Social Value Extra Capacity	223%	158%
Market Value Extra Capacity	174%	156%

Volatility spread between competition and monopoly remains

Big increase in the value of extra reservoir

Carbon Tax

$25/tCO2 = 25% increase in mc of gas

Price increase less than half the increase in marginal cost

Relative to Base Case	Competition	Monopoly
Hydro G	100%	100%
Gas G	90%	93%
Social W	98%	99%
Profit	109%	100%
Social Value capacity	115%	114%
Market Value capacity	113%	113%
Price	112%	1.01

Possibilities

Developments

- more on random demand and correlation with inflows
- other oligopoly market structures
  - oligopoly with mixed portfolios
  - oligopoly with specialised portfolios
  - other forms of competition
- Cap and Trade would be a particular challenge

References

1. Evans, Lewis, Graeme Guthrie and Andrea Lu, *A Continuous-Time Electricity Market Model and its Application to Evaluation of Effects of Climatic Change*, available at SSRN, *http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1968028, Dec 2011 20p.*