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# The Allocation of Water by the New Zealand Electricity Market: effects of particular climatic changes

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The seminar draws on two strands of research of ISCR conducted under the MOTU project 'Integrated Research on the Economics of Climate Change Impacts, Adaptation and Mitigation'.

# Road Map

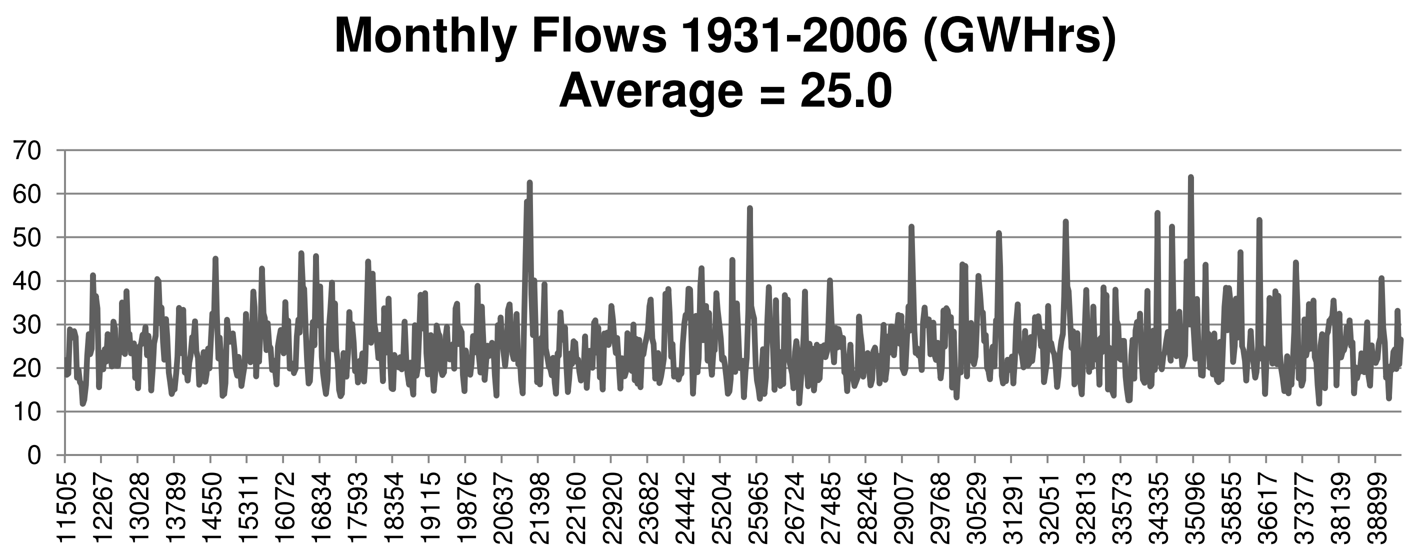
1. Inflows
2. Linkages among: Inflows, Spot and Forward Prices
3. The spot market, and water allocation
4. The spot market and climatic change
5. Forward (long term, hedge) pricing and the spot market
6. Forward pricing and climate change

# Part I
## Inflows
## the long and the short of it

# Inflows and The Electricity Market

- The spot market uses *characteristics of inflows* in the very short term
- Long term pricing and hedges are *based on spot prices* in the distant future
- Inflow short term and long term characteristics differ: as inflow today is not independent of inflow tomorrow
- Climatic change may affect long and or short term characteristics of inflows

# Inflow Characteristics for the distant future




Forecasting inflows for a month a year from now: the current inflow is not useful: inflows in these months will be independent of each other

Use

Forecast of 25 (long term average calculated from the past).

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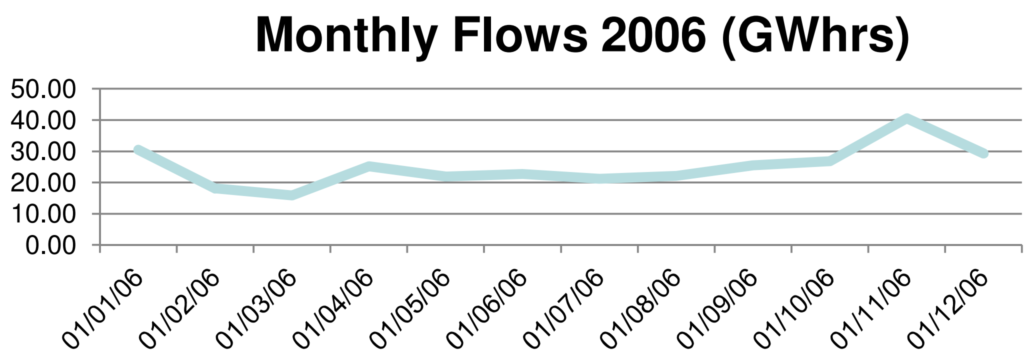
# Inflow Characteristics for the Near Future




*Short term inflows* are

- Related over time
- Affected by a) short term possible variation and b) speed of elimination of spikes

*Forecasting inflows* a month ahead the current inflow is useful because inflows only a month apart are related

use

one month forecast inflow = 15 + 0.4 *current inflow

# Inflows in the Spot Market Model

- Recognise continuity of flows
- Enable variation with climatic process
- Have randomness that reflects actual real time weather events
- Has short run variation given immediate past inflows
- Has long run variation where past inflows do not aid prediction
- vary systematically monthly (seasonality):
- Inflow process estimated from monthly data July 1931- June 2008.

# Part II

# The linkages: climate, spot and forward prices

# Spot or Hedge Transactions

- The spot market is a market for mismatches of planned/actual demand and supply by consumers and generators
- Spot prices are volatile and pose risk
- Most electricity market transactions are at prices set by forward prices (via vertical integration or hedges)
- Guide: roughly 20% of wholesale electricity transactions are at the spot price

# A Commonly used Forward Price

## Contract for Differences: sets a forward price for some amount

Buyer of amount $Q_{total}$ on spot market with a CFD for quantity $Q_{cfd}$ pays

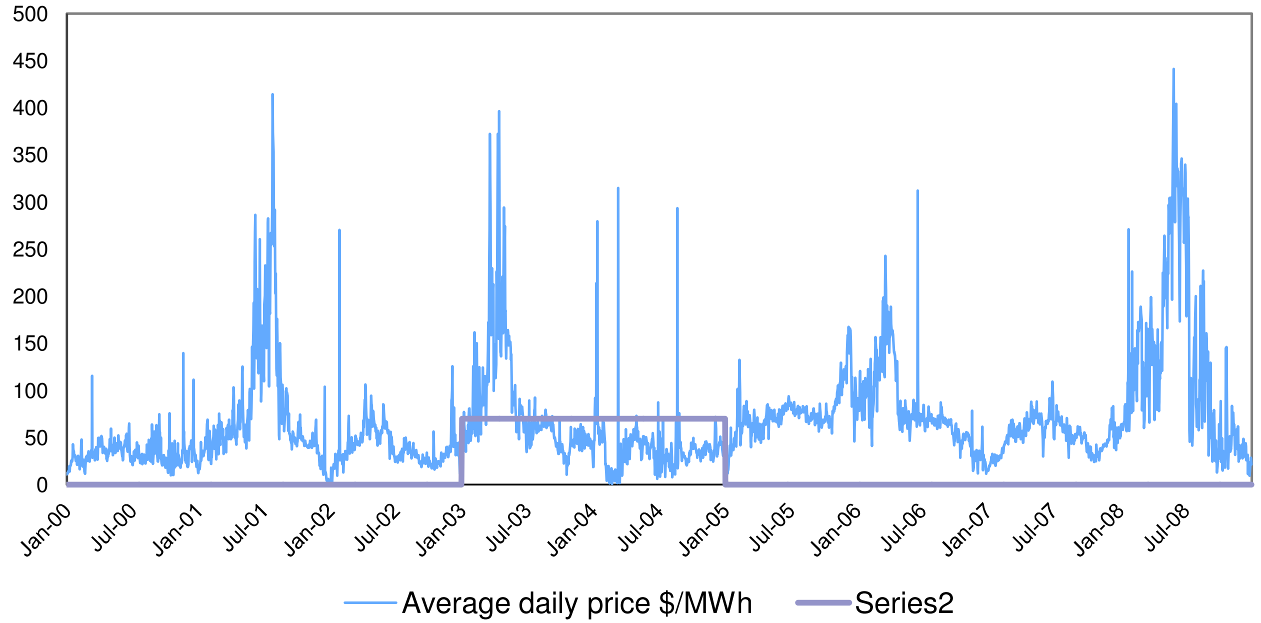
$$amount = spotprice*Q_{total} + [strikeprice - spotprice]*Q_{cfd}$$

So price actually paid (and received) is p = strike price for CFD quantity (e.g. set $Q_{cfd}=Q_{total}$ )

Design of CFD considers

a) quantity covered, b) strike price, c) period of the contract and d) location

# Example A $70/MWhr Forward Price (hedge) for 2003 and 2004 (for some quantity and location)




This CFD implies a transaction price for the amount of the contract of $70/MWh

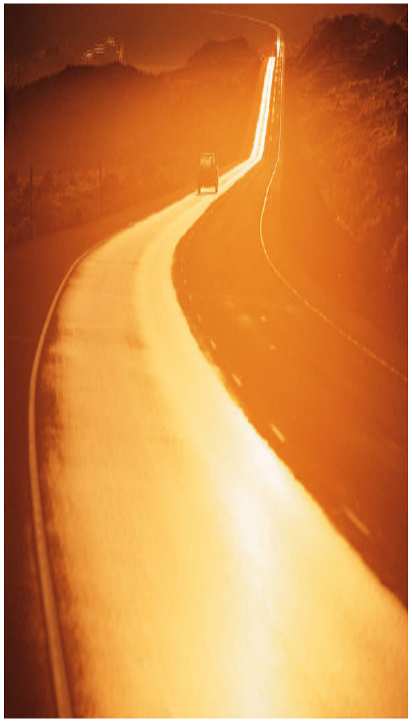
It will usually have been written well in advance of Jan 03

# The Linkages

Expected
Spot price
characteristics

*Supply* cost of generation plant/fuel, *Demand*, Climate and events

The Future



The Present

Spot Prices
Inflows, Storage
Short term demand
supply and transmission events

Forward Prices

# Part III
# the Spot Market
# and Water Allocation

# The Electricity Spot Market Model: I

**The market model** is in continuous time since rivers flow continuously and electricity supply must equal demand at each instant in time

**Each day** is split into peak (8 hour) and off peak (16 hour) periods:

**Each year** is divided into summer, fall, winter and spring seasons

**Demand -** is linear and shifts occur between peak and off-peak

- is seasonal: peak and off-peak demand vary by month

- slope determined by literature

**Model is calibrated** to NZEM 2007

# The Electricity Spot Market Model II

**Electricity Supply** from hydro and gas generation

**Location** Gas plant assumed closer to consumers:

- hence cost of transmitting electricity from gas generators to consumers is less than transmission cost for hydro plants,
- hence some gas generation always occurs

**Gas generation**

- is non hydro
- has marginal cost increasing
- has industry plant capacity limitation

# The Electricity Spot Market Model III

**Hydro generation**

- has no running cost or reservoir service costs (or these are fixed costs)
- is limited by inflows and the amount of stored water, and
- has plant capacity limitation

**Reservoirs**

- store water from inflows not immediately used in generation
- shift water availability between time periods (very small potential effect on total annual water for generation)
- have capacity limitations

# The Electricity Spot Market Model IV

**Market behaviour**

•is assumed competitive, equivalently as if generation decisions are taken by a social planner that has the objective of maximising the present value of total surplus looking forward from any date.

**Planner behaviour**: at any point in time, the planner has to

•decide how much hydro and gas generation to run (ie *its generation policy*)

- given stored water, current inflows and knowledge of past inflows;
- taking account of the potential use of the stored water in the future,

**The planner at any date**

•weighs up the gain in total surplus from use of water in current generation, vs expected surplus from future use over some future indefinite period;

•based upon knowledge of the market, the distribution of inflows and past inflows.

# The Electricity Spot Market Model V

## Generation Policy

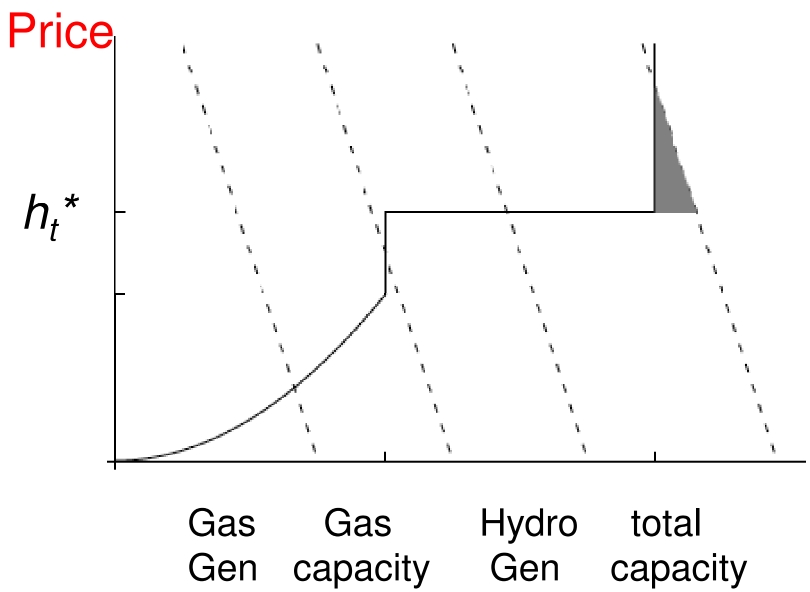
**The planner's choices**: simultaneously, in each trading period

1 Value the stored water as an asset and set a value ($h_t$) such that the asset earns no abnormal return (by delayed use or immediate use)

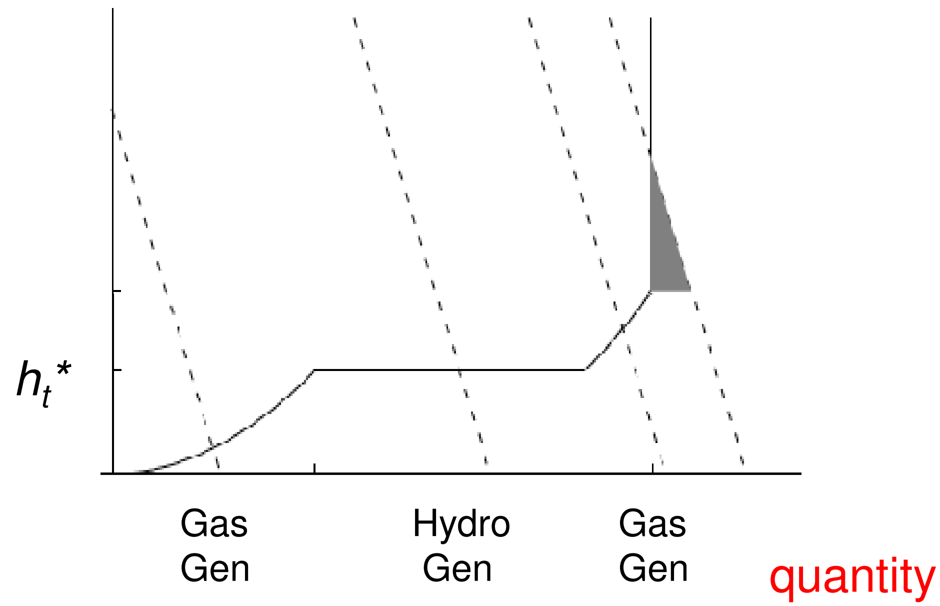
2 Choose amounts of gas and hydro generation (the policies) taking ($h_t$) as the price of water. Do this by setting the consumer price to the marginal cost of each of gas and hydro

# Generation Policies:
## Two Possible Situations in any Trading Period

I Value of stored water high:
all gas used before hydro generation




II Value of stored water low:
gas then hydro then gas generation to capacity



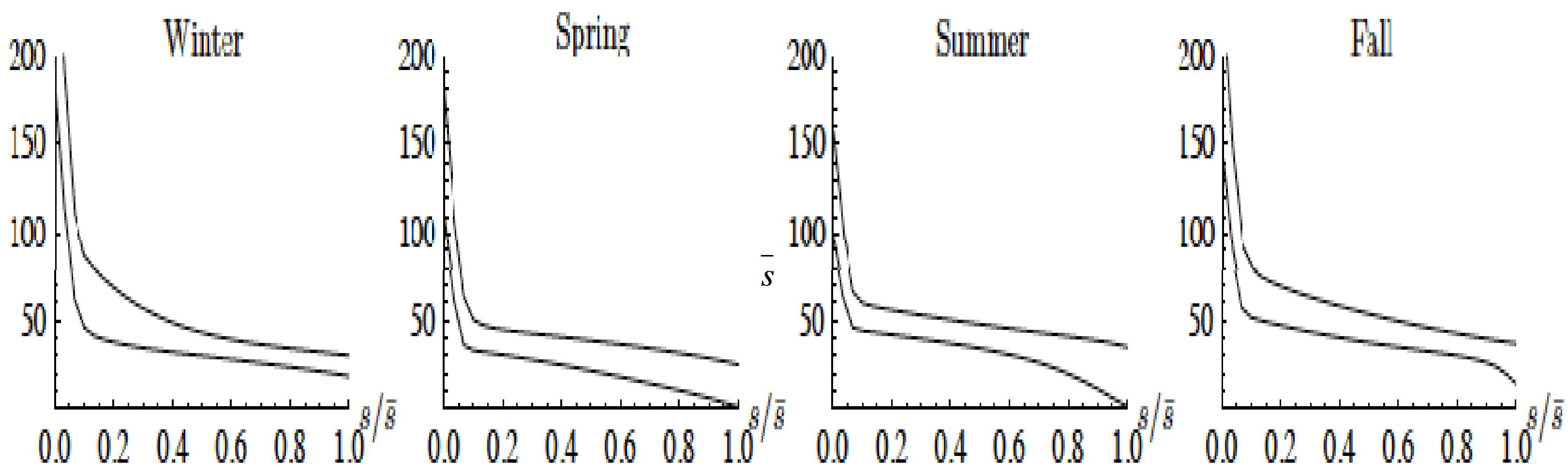

*h** = value of water adjusted for cost of transmission to consumers

*h* assumed to be constant within a day: peak and off peak

Shaded area: welfare cost = value of lost load due to demand > system capacity

# The Value ($h_t$) of Water

**Model outcomes from 200 years of simulated daily data**

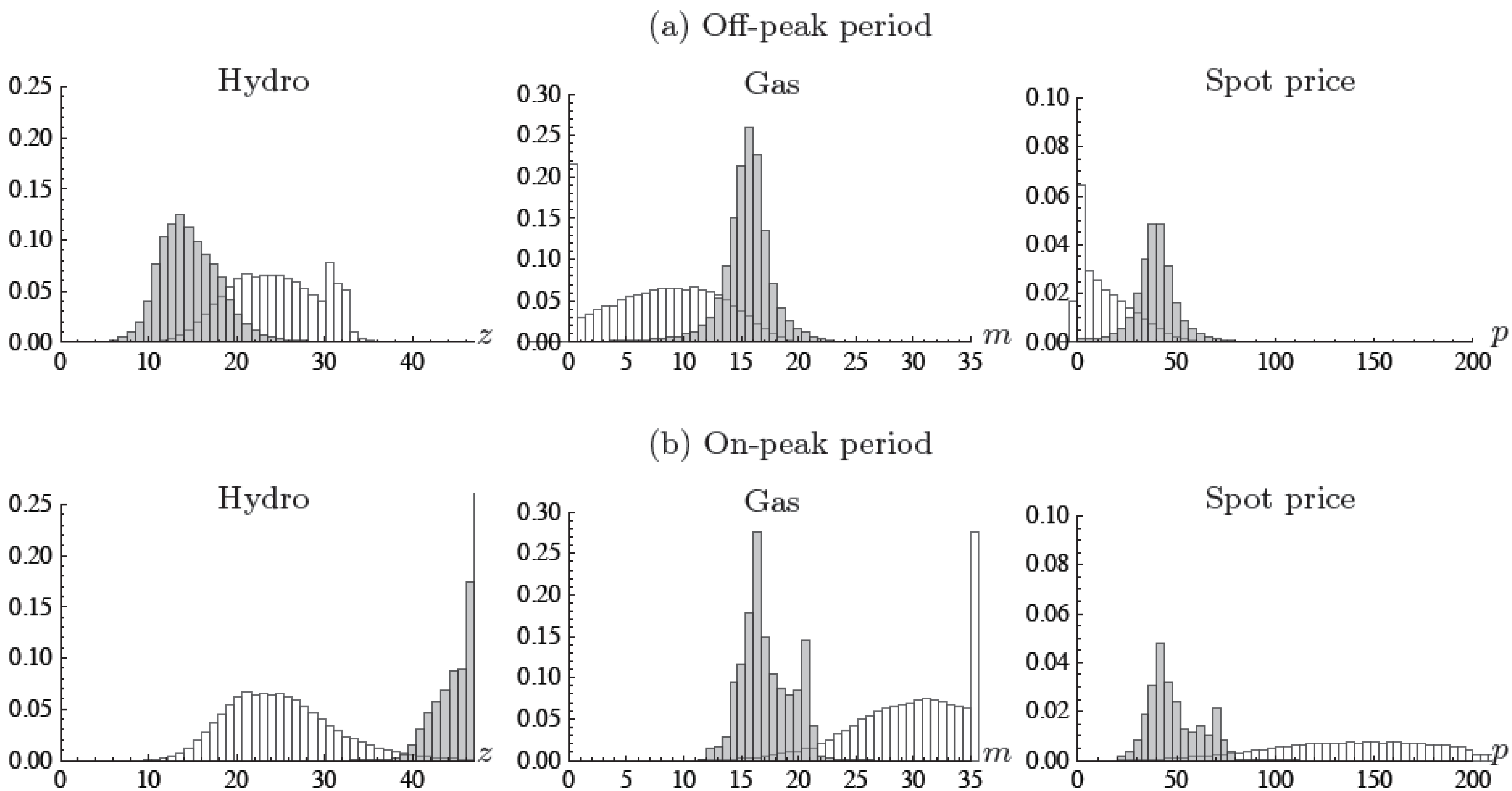



- $s/\bar{s}$ is the proportion of storage to capacity
- The upper curve depicts h for very low inflows
- The lower curve depicts h for very high inflows

# Within-day Generation Policy or Water Allocation

light-shade without reservoir || **dark-shade with reservoir**

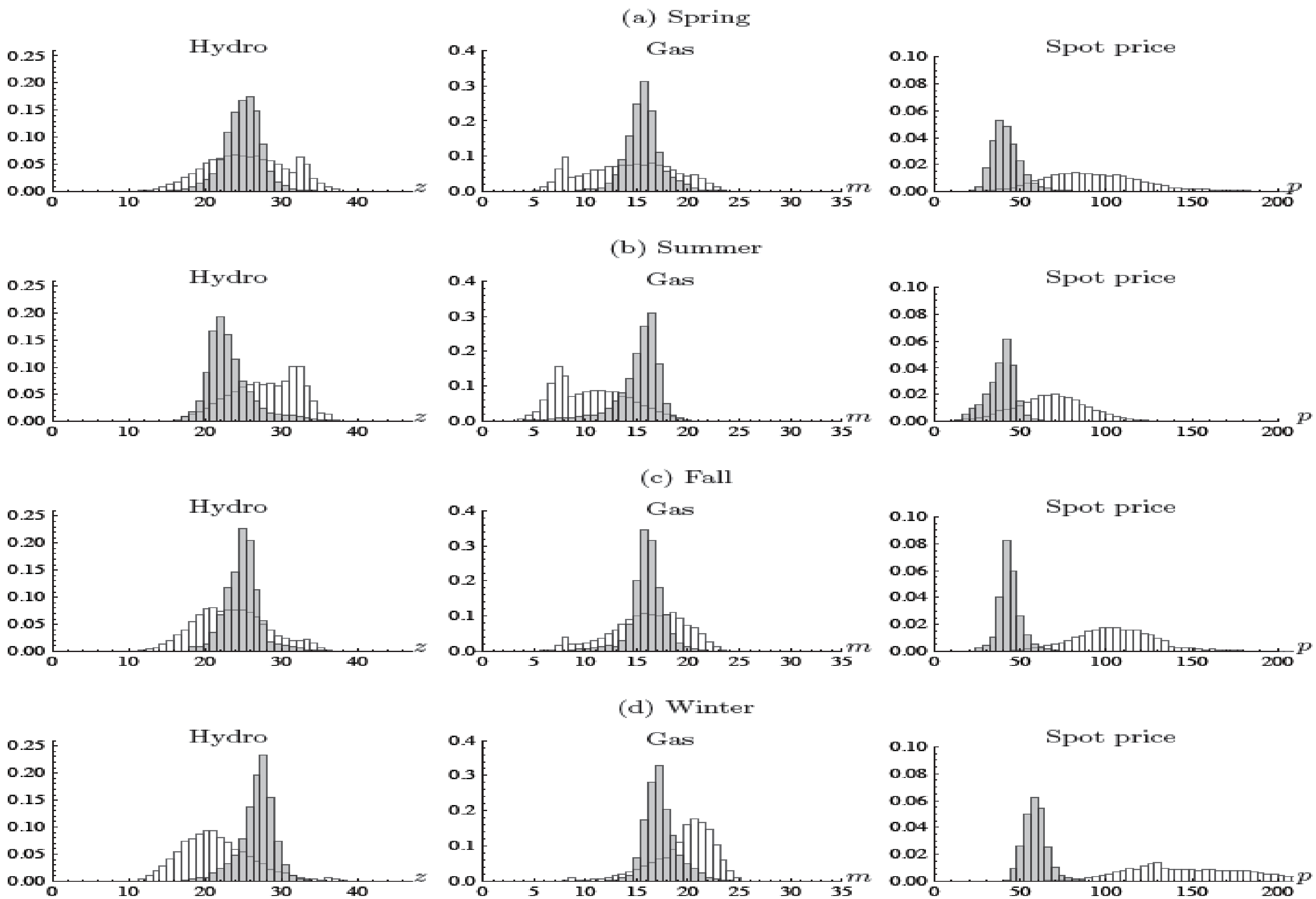
Outcomes from simulations



# Seasonal Generation Policy or Water Allocation

light-shade without reservoir || **dark-shade with reservoir**

Outcomes from simulations:

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# Variation in Market structure: same inflows

Summary outcomes from simulations: variations vs baseline

- **Value of lost load** is very low at calibrated reservoir capacity:

- **Increase/decrease in reservoir capacity**
  - little effect on on/off peak prices
  - affects seasonal prices
  - increases/decreases consumer and total surplus (not so producer surplus)

- **Expansion in hydro capacity** increases consumer surplus at the expense of producer surplus as more substitution is possible lowering winter peak prices

- **Increase base load generation** (moves marginal cost curve out)
  - reduces storage and use of hydro as gas substitute at peak seasons
  - increases total surplus
  - increases/decreases producer/consumer surpluses

# Part IV
# The Spot Market and Changes
# Climatic, or Inflow Characteristics,

# Variation in Climate: i.e. in the Inflow Process

**Summary outcomes from simulations: variations vs baseline**

1. **Reduction in average inflows by 25% seasonality unchanged**
   - means annual hydro generation capacity is reduced but reservoirs able to be fully utilised
   - producer surplus up (hydro and gas) total and consumer welfare down

**2. Reduction (scaling down by 25%) in the perfectly predictable component of inflows with unchanged average inflows (ie weaker seasonal inflow variation)**

reduces use of storage:

- Intra day: smaller (larger) peak/off peak spread hydro (gas)
- Seasonal: larger (smaller) peak/off peak spread hydro (gas) (because of increased winter inflows)
- Little change in welfare (small increase/decrease in consumer/hydro surpluses)

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# Variation in Climate: i.e. in the Inflow process

**Summary outcomes from simulations: variations vs baseline**

3. **Reduction in predictability of inflows** (increase short run volatility by 25%, and consequently long run variability)
   - Reduces ability to plan, and inter-temporal fuel substitution
   - Price spread widens intra-day and seasonally and narrowed gas and hydro generation spread

4. **Mean reversion (rate of) increase by 25% (** and short run volatility increase such that long run variance is unchanged)
   reduces use of storage:
   - Intra day: smaller (larger) peak/off peak spread hydro (gas)
   - Seasonal: larger (smaller) peak/off peak spread hydro (gas) (because of increased winter inflows)
   - Welfare: little change (small increase/decrease in consumer/hydro surpluses)

# Variation in Climate IV: carbon tax $25/tCO_2$

**Summary outcomes from simulations: variations vs baseline**

•Increases the marginal cost of gas fired generation

•Reduces the use of gas generation

•Average hydro generation not much affected, but less is used in seasonal peaks, raising price and reducing total surplus from the electricity market; although increasing surplus to hydro and gas generators.

# Part V

## Forward Prices and Future Spot Prices

# Spot and Forward Prices: generators

- The electricity process – no economic storage – means that the relationship between spot and forward (strike) prices differs for electricity from that of financial and other commodity markets.

- Approach assumes absence of "complete markets" and
  - the generator is risk averse and maximises the present value of expected utility by looking forward and reasoning back
  - The generator chooses

| t=0 | | t=1 | | t=2 |
|---|---|---|---|---|
| *Amount of hedge chosen* | *climatic information revealed (inflows)* | *generation offer to the spot market* | *events & climate revealed (temperature)* | *spot market determines spot market price/quantity* |

  - Result: the generator generally has a positive supply of hedges

# Spot and Forward Prices: retailers

- Approach assumes absence of “complete markets” and
  - the retailer is risk averse and maximises the present value of expected utility by looking forward and reasoning back
  - Retailer (committed to a share of aggregate final demand) chooses

| t=0 | | t=1 | | t=2 |
|---|---|---|---|---|
| *Amount of hedge chosen* | *climatic information revealed (inflows)* | *demand share input to the spot market* | *events & climate revealed (temperature)* | *spot market determines spot market price/aggregate quantity* |

  - Result: produces demand for hedges by retailers

# Spot and Forward Prices: Market for Hedges

- Supply equals demand for hedges jointly determined with the market clearing (strike) price at t=0

t=0 — *Hedge market clears*

*climatic information revealed (inflows)*

t=1 — *inputs to the spot market (temperature)*

*events & climate revealed*

t=2 — *spot market determines spot price/quantity*

- There exists a hedge market where hedge prices/quantities will be affected by future spot price distributions that themselves are affected by climate change.

# Market for Hedges I

- The results (from a stylised model calibrated to the NZEM) are that
  - Hedges are integral to the wholesale electricity market,
  - The quantity and price of hedges depend on the extent of risk aversion of retailers and generators, and the mean and volatility of prices
  - The quantity and price of hedges will also depend upon spot market shares of market participants
  - Firms that have spot market market power (large share of spot market) choose to hedge
  - Illustrating that there is a trade-off for generators: reduced risk from hedging comes with reduced spotmarket power

# Market for Hedges II

- Vertical integration is very very similar to hedges: differences generally arise from the terms of hedges (eg CFDs) vs supply contracts to consumers

- Gentailer (retail+generation) firms participate in the hedge market but much less than vertically separated generators and retailers

- The origins of hedge parameters matter: an increase in hedge price given hedge quantity will affect welfare by its effects on investment, transactions costs and cost of capital.

- Climate change will affect future spot prices and so affect hedging parameters and positions

# Part VI

# Forward (or Hedge) Prices and Inflow Process Change

# Hedges and Climate Change I

- Assuming hedges that span sufficient trading periods to be long run (eg not day ahead): climate change will affect hedge quantities and prices by its effect on
  - the long run expected future level of spot prices, and
  - the long run variation of spot prices

- An expected increase in either the expected spot price or the volatility of the spot price can be expected to increase the quantity (price) of hedges given the price (quantity) of hedges*

* Aside: in the model these statements hold for particular assumptions

# Hedges, Structure & Climate Change II

**(changes in long term spot price process: using simulations)**

| Relative to the base case | Expected spot price | Volatility of the spot price | Hedge Price \| quantity |
|---|---|---|---|
| Base load gas generation (25%) increase | 1.01 | 1.40 | up |
| 25% lower average inflows | 1.49 | 0.79 | ? |
| 25% weaker seasonality in inflows | 0.99 | 0.98 | down |
| Reduction in predictability of inflows | 1.01 | 1.14 | up |
| Increase in speed of mean reversion of inflows | 0.99 | 0.94 | down |

# Final Comment

- Hedge and spot markets are integral parts of a wholesale electricity market: no matter the state of competition
- Market power in the spot is reflected in the terms of hedge contracts; and spot market offers are affected by hedge positions
- Models of decisions about offers and bids on the spot *and* hedge markets must consider each market and risk.
- Long run forward prices are determined by long run spot prices; but these prices are determined by short run characteristics of inflows of the time and these chatacteristics may change with climate
- Modelling situations where there are storage options should properly recognise them.

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# Sources

- "The Role of Storage in a Competitive Electricity Market and the Effects of Climate Change", with Graeme Guthrie and Andrea Lu, forthcoming, *Energy Economics*, 2012

- "Essays on the interaction between risk and market structure in electricity markets" ch. 6 of PhD Thesis, Gabriel Godofredo Fiuza de Bragana, 2011