The Role of Storage in a Competitive Electricity Market and the Effects of Climate Change

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NEW ZEALAND INSTITUTE FOR THE STUDY OF COMPETITION AND REGULATION INC.

Outline

1. New Zealand Market Characteristics
2. The Spot Market, Climatic and Forward Price Links
3. The Spot Market Model and Water Allocation
4. The Spot Market Allocations and Climatic Change
5. Comment

New Zealand Electricity Market Characteristics

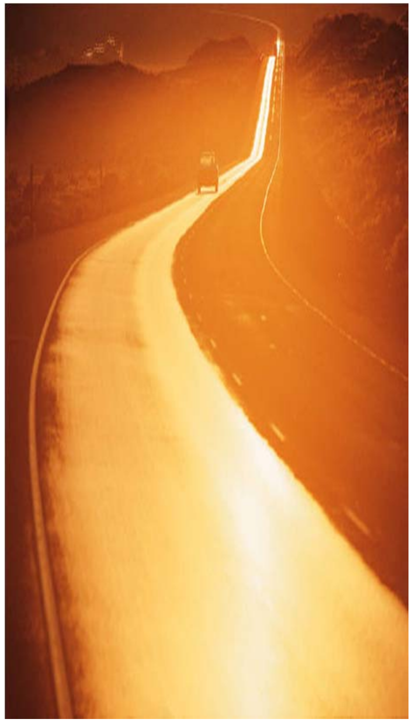
- Generation
  - 55-60% hydro
  - 17-20% gas, coal (5%)
  - 15-20% other: geothermal (13%), wind (4%)
- 5 generators produce some 95% of total electricity
- Compulsory pool, UOP auction
- Vertical integration of retail and generation
- Hydro has limited storage and depends upon reservoir inflows that are volatile and seasonal

Linkages: spot market, climate, and forward prices

Expected
Spot price
characteristics

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

The Future



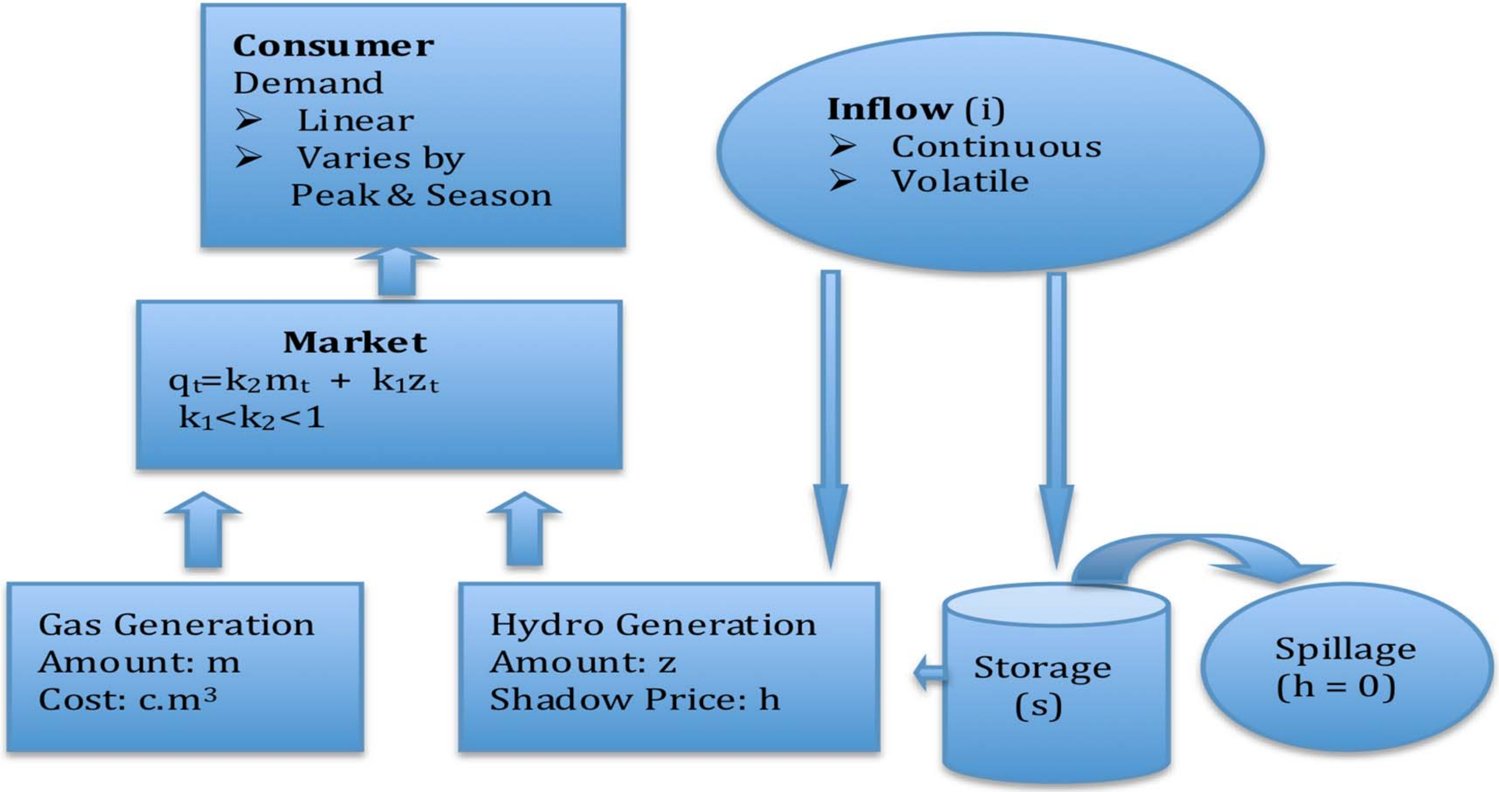
The Present

Forward Prices

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

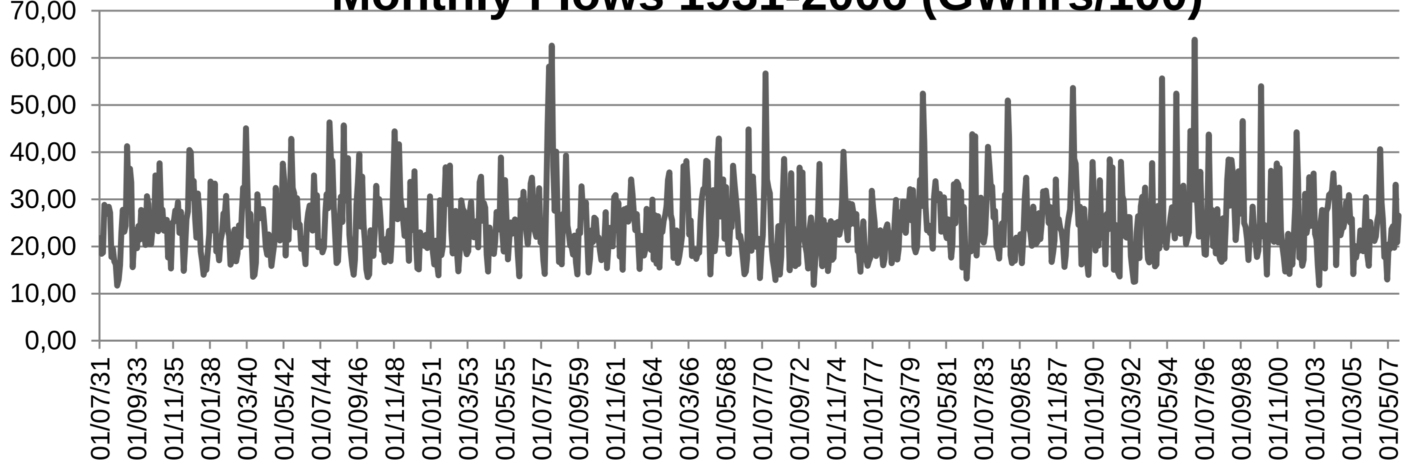
Market Model: structure

in continuous time

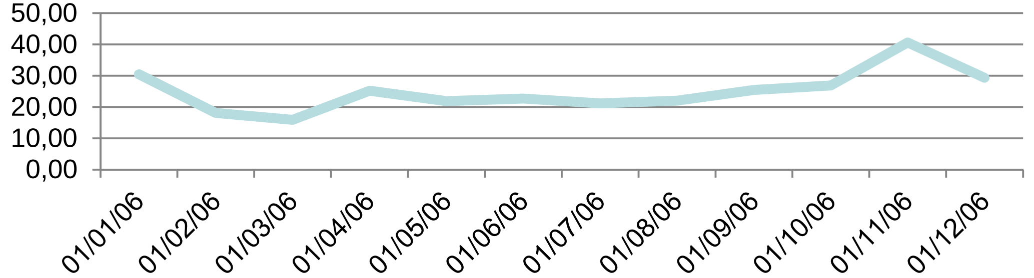


Inflow Characteristics

Monthly Flows 1931-2006 (GWhrs/100)



Monthly Flows in 2006 (GWhrs/100)



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Market Model: inflow process

Inflow Process

$\boldsymbol{i_t} = \mu(t) y_t$ * in units of electricity

$dy_t = \frac{\eta^2}{2}(1 - y_t)dt + \sigma\eta\sqrt{y_t}d\xi_t$ * estimated from 1931-2008 monthly inflows

$\mu(t)$ * monthly constant
* estimated as monthly mean inflows

Short Run Characteristics

η determines speed of mean reversion; and affects variation

σ affects extent of variation of inflows

Long Run Characteristics (Unconditional Distribution)

$\boldsymbol{E}y_t = 1$ and St. Dev. (y) $= \sigma$ so $E i_t = \mu(t)$ and St. Dev. (i) $= \mu(t)\sigma$

Market model:
Full trading period has off and on peak

- **For any interval dt** ($\tau_{on}+\tau_{off}=1$)

On-Peak period (8/24): $\tau_{on}dt$ Off-Peak period (16/24): $\tau_{off}dt$

- **Demand intercept, x, differs by on-off peak and season:** is calibrated from averages of load

- **Consumption of full trading period is off peak plus on peak consumption**

Market Model: further details

Gas generation

- is non hydro
- has increasing marginal cost ($c(m)=c.m^3$)

There are:

- Gas and hydro plant capacity limitations
- Reservoir capacity limitations on storage
- Months allocated to four seasons

Model Calibration: 2007

Simulate calibrated model for 200 years daily full trading periods

Market Model: behaviour

- Competitive behaviour equivalent to social planner choice

- In any full trading period choose on- and off-peak hydro and gas generation to maximise the expected present value of total surplus:

  - looking forward to the indefinite future

  - given the model's structure, distribution of inflows,
    levels of current inflow and storage

  - given that only resource with opportunity cost is gas

- Planner's choice produces gas and hydro generation policies

Market Model: generation policies

in each full trading period

- Gas and hydro generation policies are such that in each on/off-peak period the cost of hydro and gas generation

$$h.z \quad + \quad c(m)$$

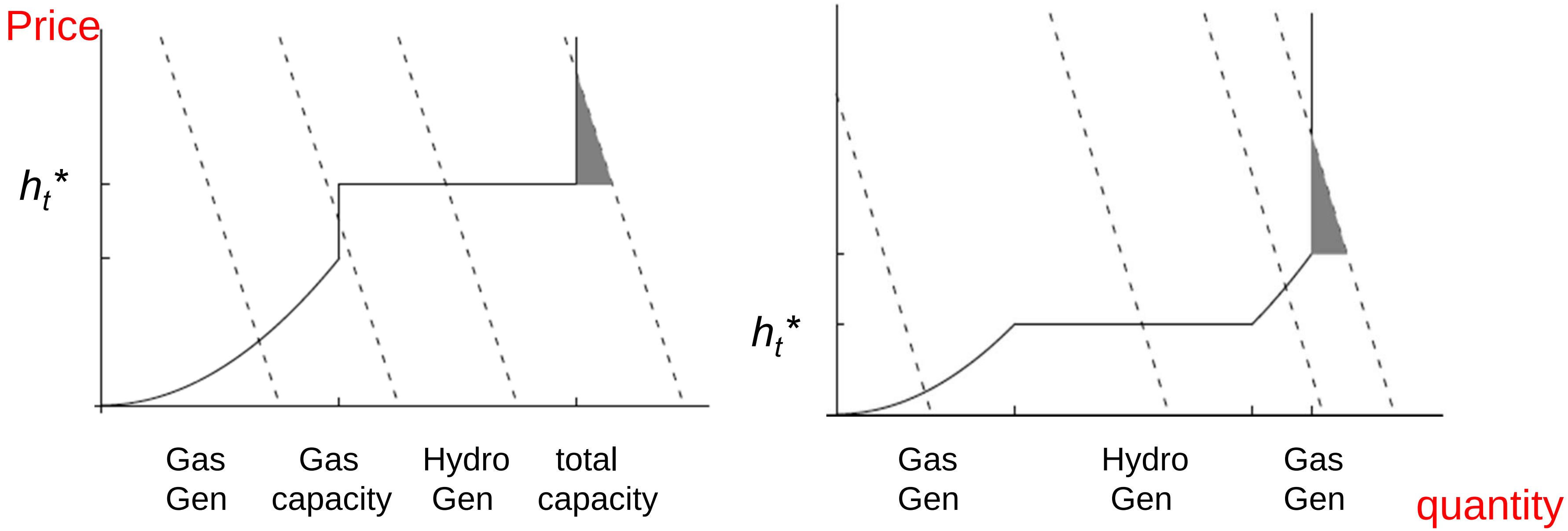
  is minimised and consumer price equals marginal cost

- Where h is the expected increase in future total surplus produced by storing an extra unit of water

Generation Policies:
Two Possible Situations in any Trading Period

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

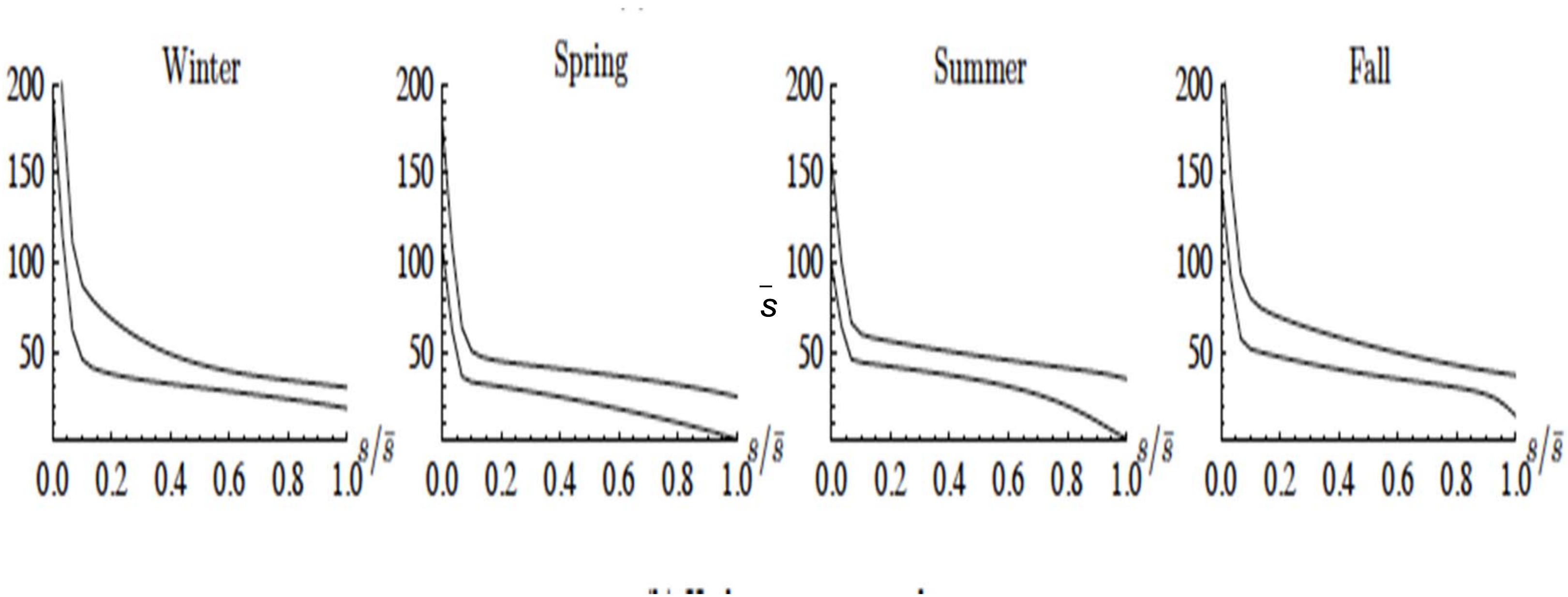
II Value of stored water low:
gas then hydro then gas generation to capacity



- *h** = value of water adjusted for cost of transmission to consumers
- *h* 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 (full trading) periods

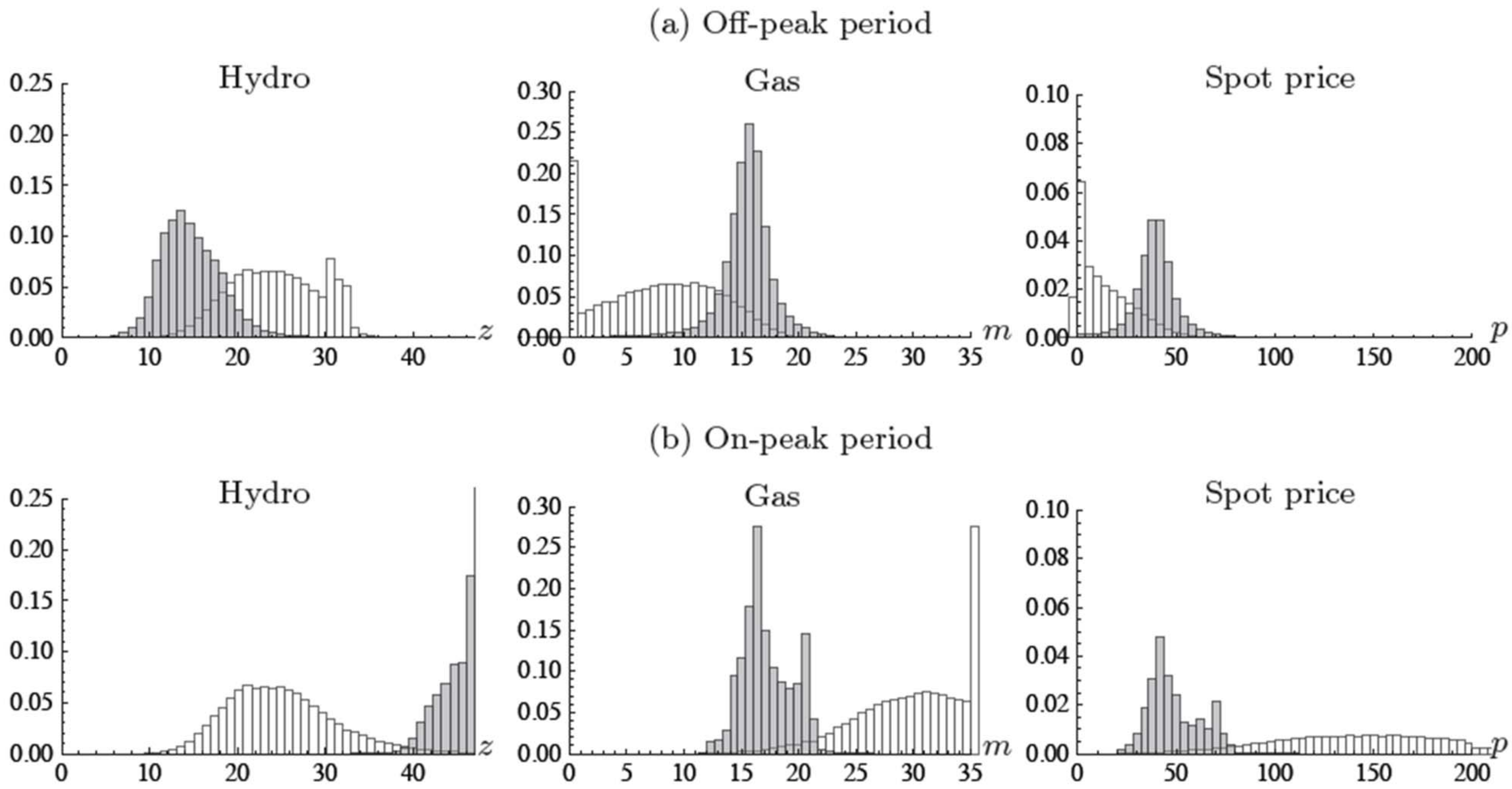


- $s/\bar{s}$ is the proportion of storage to capacity
- The upper curve depicts h for very low inflows
- The lower curve depicts h for very high inflows

Within-day Generation Policy/Water Allocation

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

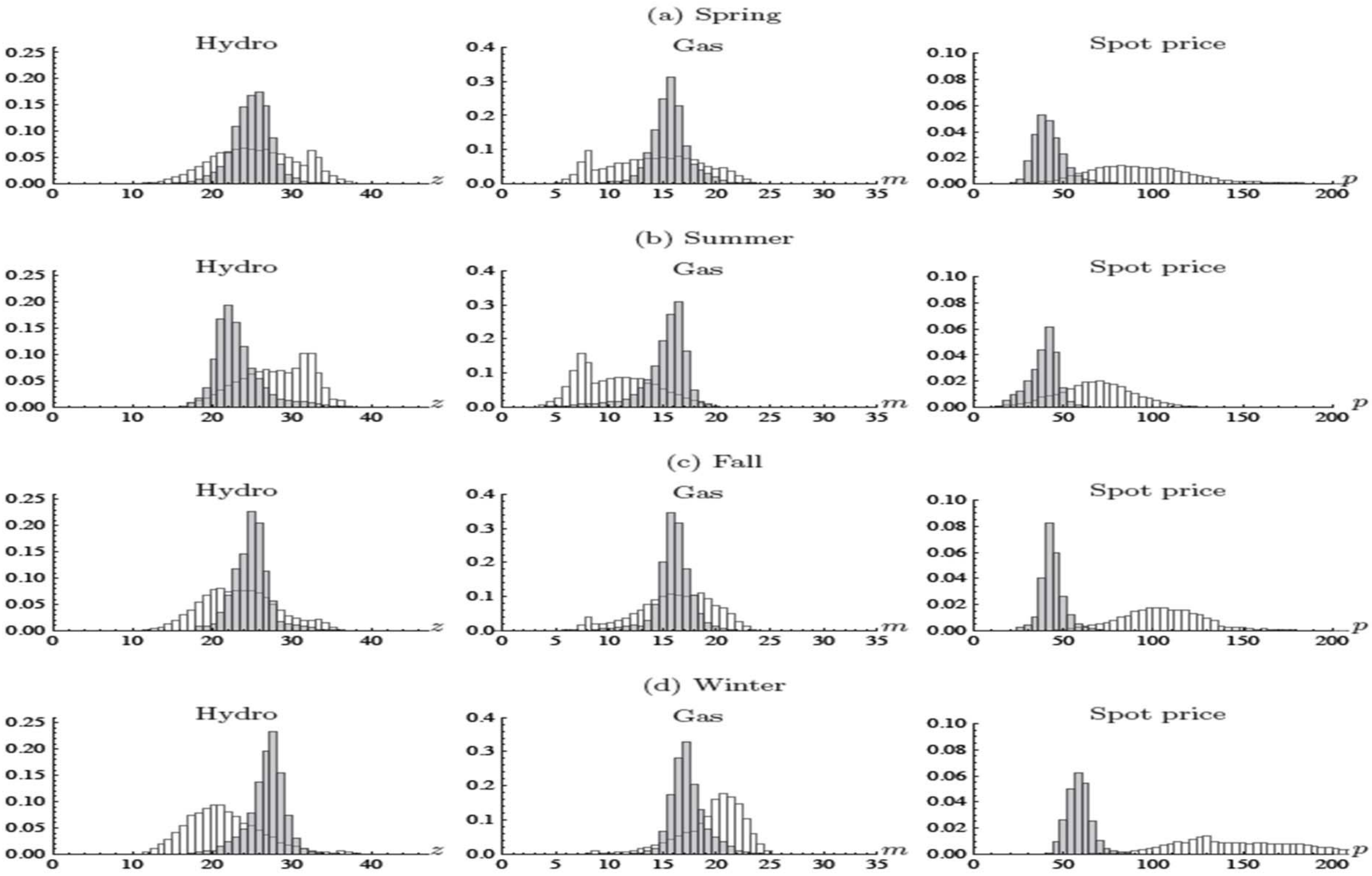
Outcomes from simulations



Seasonal Generation Policy/Water Allocation

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

Outcomes from simulations:



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Variation in Market structure: same inflow process

Summary outcomes from simulations: variations vs baseline

- **Value of lost load** is very low at calibrated reservoir capacity:
- **Increase in reservoir capacity**
  - little effect on on/off peak prices
  - affects seasonal prices
  - Increases 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

Effect of Changes in
Climatic, or Inflow Characteristics,

Variation 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 (for hydro and gas), total and consumer welfare down

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

   reduced use of storage:
   - Intra day: smaller hydro peak/off peak spread: gas the reverse
   - Seasonal: larger peak/off peak spread hydro (because of increased winter inflows): gas the reverse
   - Small increase in welfare (in consumer welfare/and decrease in hydro generator surpluses)

Variation 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
   - Small decreases in total and consumer welfare

4. **Mean reversion rate increase by 25% (** and short run volatility increase such that long run variance is unchanged)

   reduces use of storage:
   - Intra day: smaller peak/off peak spread hydro (gas is reverse)
   - Seasonal: larger peak/off peak spread hydro (gas is reverse) (because of increased winter inflows)
   - Welfare: little change

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.

Final Comments

- The changes in inflow characteristics and forward price link: *spot-price* effects of climate change
  - Lower average inflows: raised average price and lowered volatility
  - Weaker seasonality reduced price average and volatility by small amounts
  - Reduction in the predictability of inflows raised average and volatility
  - Increase in speed of mean reversion lowered both average and volatility

- Other issues