climate change: *winners* and *losers* in NZ's electricity market

Lewis Evans and Graeme Guthrie employ their dynamic continuous-time model of the New Zealand electricity spot market to provide insights into the effects that climate change – and policies such as the Emissions Trading Scheme (ETS) – might have on key market-performance indicators[1]. They find that ETS solves some problems but creates others.

A framework that usefully assesses the effect of climate change on an electricity market's performance should incorporate the salient features of electricity production and consumption that are susceptible to climatic variation and have explicit links to relevant natural-resource characteristics. For New Zealand's electricity market, this requires recognition that hydro generation accounts for some 55% to 65% of generation capacity, that the capacity of storage lakes is low, and that inflows into these lakes naturally fluctuate.

River-flow characteristics together with reservoir-storage constraints mean that generation decisions must be based on expectations about a risky future as well as on current and past weather, demand, and storage.[2] Many static electricity-market models rely almost exclusively on observed contractual information about marginal costs. This model differs because it employs a forward-looking approach that reflects both historic information and future uncertainties. Specifically, it captures the effects of:

- resource-availability uncertainties
- decisionmaking that trades off the returns from storing water for future generation against the returns from generating now, given the actual and anticipated costs of fuel for alternative generation (in New Zealand, this is gas-fired generation).

It does this by treating stored water as an asset.

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[1] This article draws upon the work of Lewis Evans, Graeme Guthrie, Andrea Lu and John Nash. For more detail see: L Evans, G Guthrie and A Lu (2010) 'A New Zealand Electricity Market Model: Assessment of the effect of climate change on electricity production and consumption' (available at www.iscr.org.nz/f585,16761/16761_NZ_Electricity_Market_Model.pdf).

[2] L Evans and G Guthrie (2009) 'How options provided by storage affect electricity prices' *Southern Economic Journal,* 75(4) pp681-702.

Stored water must satisfy the asset pricing equation:

required return = current period pay-off plus expected future capital gain

Hydro and gas generation are managed in order to maintain this relationship. Hydro-generation decisions are based on the shadow price, or value, of the water that is a by-product of this asset-equilibrium condition. Expectations are concerned with future inflows and resulting (future) price and quantity outcomes. As there is some correlation of inflows between periods, inflow expectations are informed by past inflows. For firms the required rate of return is measured as profit; and for society it is measured as total welfare (in economists' jargon: consumer plus producer surplus). Provided that generation is unconstrained by the capacity of plant or limits of storage and that gas availability is unconstrained at its market price, the shadow price of water will equal the cost of an extra unit of gas-fired generation.

Start here: the electricity market

Figure 1 gives shows the market model, with these assumptions:

- Consumer demand for electricity is uncertain.
- Generators supply this demand from a combination of hydro generation and gas generation, depending upon the relative costs of each up to the maximum generation capacity for each type.
- Water flows continuously into storage lakes, but the rate of inflow varies a lot.
- Water can be used directly for generation, be stored or (if the lake is full) be spilled.

Partly because demand must equal supply at each instant in time and spot-market trading periods are short, the structure of Figure 1 is implemented at each instant of time.

A social planner will seek to maximise the expected present value of total welfare produced by the electricity market; a monopolist will seek to maximise the expected present value of profits. Our model compares market outcomes under each of these two objectives, termed respectively 'competition' and 'monopoly'. It is calibrated to the New Zealand market at an aggregate level.

A process for the inflows is estimated for the New Zealand market as a whole and used to simulate inflows for a 30-year period. A 'solution' is found for each daily trading period by finding the optimal hydro and gas generation and storage for each day of the 30 years, based on current and past inflows, the generation- and storage-decision rules, and the state of the system each day.

Tweaking the base case: 'competition' and 'monopoly'

Under 'competition' we found that the market price varied considerably, period by period, but was less volatile than inflows. This comparatively lower variation in prices occurred because both water storage and gas generation can be used to reduce the volatility of hydro generation. Large price falls are associated with a low shadow price of water, which itself coincides with high levels of storage and inflows. Welfare is affected by the structure of supply and demand, by fluctuations in inflows and demand, and by the level and degree of forecastability of inflows.

By comparison 'monopoly' resulted in higher prices and lower welfare, as expected. Storage levels were also higher. Notably, gas generation was much reduced – as was volatility in generation, consumption price and welfare. This is because gas generation has a real financial (fuel) cost that hydro generation lacks; and so the monopolist, in cutting back on aggregate generation to raise revenues and profits, chooses to reduce gas generation. (In consequence, it is less costly for the monopolist than for the social planner to manage fluctuations in inflows by varying gas generation.)

The lower volatility under 'monopoly' is significant and is not reflected in the welfare calculation. It is as though the 'monopolist' does not run the system as hard as 'competition' would; and if lower volatility had a real social cost attached to it, the difference in welfare loss from 'monopoly' (relative to 'competition') would be considerably reduced.

To assess the effect of additional storage, the base models were also simulated with a higher reservoir capacity. Increasing current storage capacity by 23% in the 'competition' scenario significantly increased producer surplus but left consumers worse off. In the 'monopoly' scenario, both the consumer and the producer surpluses (total welfare) increased. These results reflect the shape of demand – which in turn reflects whether consumers or producers benefit more-or-less from stabilised prices and also that, under 'competition', water inflows are fully utilised over the 30 years (under 'monopoly', the expanded storage would induce more output).

Add climate change …

Climate change affects both average inflows and fluctuations in inflows. Changes in average inflows will affect the performance of the electricity market because it amounts to a change in fuel supply over any significant period. Changes in the fluctuations of inflows will affect decisionmaking, but will not provide more fuel over the 30-year period.

The National Institute of Water & Atmospheric Research (NIWA) forecasts that average inflows are likely to increase with climate change. However, we examined the opposite: a decrease in inflows. Table 1 summarises the results of two additional scenarios – reducing inflows by 30% and increasing inflow fluctuations by 30% – relative to the base case.

Reducing average inflows by 30% decreases total generation, induces substitution of gas for hydro, reduces welfare, and substantially reduces the value of additional storage capacity. These findings are unsurprising: the reduction in average inflows increases the shadow price of water, leading to more gas generation. The higher proportionate use of gas by the monopolist reflects the monopolist's low base-case gas generation. Consequently the price does not increase to the same extent in the 'competition' and 'monopoly' scenarios. Reduction in the value of storage is induced by a lower demand for shifting hydro generation between time periods and by a lower likelihood of spilled water (which is a result of the reduced average inflows).

By contrast, if the predictability of inflows falls, so will generators' abilities to forecast particular future benefits from stored water. Consequently, the value of additional storage capacity is much greater with higher volatility of inflows than under the base case. While there is little change in *average* prices or welfare, these are much more variable. The difference between 'competition' and 'monopoly' in the volatility of outcomes remains unchanged, however.

… and some carbon tax

Implementing the ETS in any realistic model is complicated because the carbon price can be expected to be volatile and the ability to generate will be affected by the availability of carbon units: the result will be roughly analogous to managing inflows for hydro production. Instead, we consider the effect of a carbon tax. The results are reported in Table 1, relative to the base case of no such tax.

The carbon tax raises the marginal cost of (and hence causes a reduction in) gas generation, but there is little change to hydro generation. This result reflects that water is generally fully utilised under both 'competition' and 'monopoly' over the 30-year period. Under 'competition', the shadow price of water rises, as expected, with the increase in the gas cost – and so does the market price, albeit by only half the increase in the marginal cost of gas. (This sharing of the burden between consumers and producers is a standard effect of taxes.) Total surplus falls, but more under 'competition' than under 'monopoly'. The producer surplus is higher with the carbon tax than in the base case, because hydro generators benefit from price increases (their fuel costs do not alter).

A mixed result

Overall, the results suggest that climate change will significantly reduce/increase total welfare from the electricity market as average inflows decrease/increase. It also suggests that the increased unpredictability of inflows has small effect on welfare (although it does increase the social value of storage capacity). However, producers and consumers are likely to value the benefits of increased storage differently.

Carbon taxes will increase prices and reduce total welfare slightly, and will likely exacerbate producer/consumer tensions as higher prices lead to higher profits from hydro generation. Carbon taxes have little effect on the merits of additional storage.

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Aleck: Table and Diagram follow

Figure 1: The electricity market

ALECK: Please remove "The Market" from inside the diagram and also make the subsequent words in each line within the blue boxes into lower case (ie Demand, Generation, Generation, Price). Also pls can we fit "Consumer demand" (first blue box) on to 1 line?

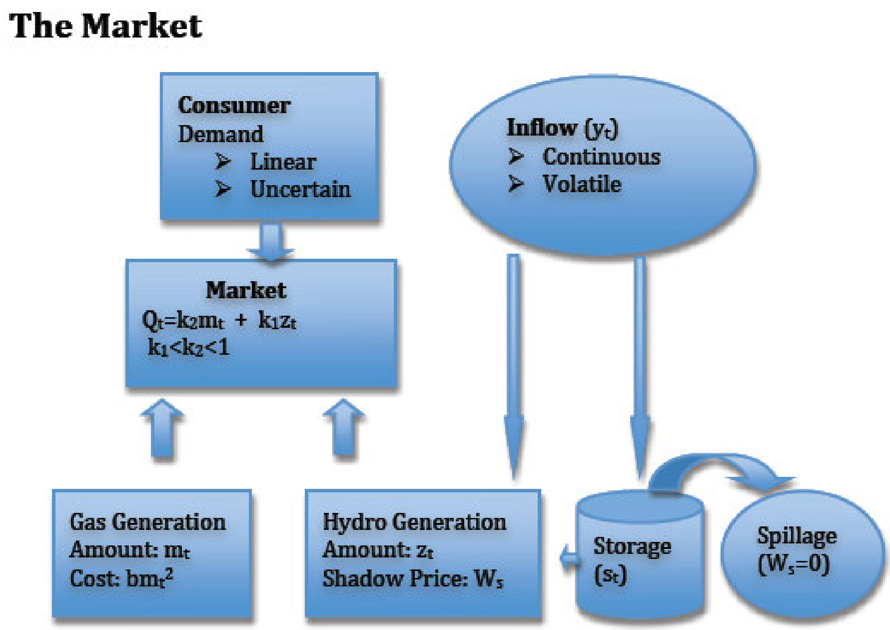

Table 1: Climate-change scenarios relative to base case

Change	Relative to base case	Competition	Monopoly
Average inflows reduce by 30%	Hydro generation	70%	71%
	Gas generation	126%	283%
	Price	124%	107%
	Social welfare	91%	93%
	Profit	104%	96%
	Social value of extra capacity	31%	17%
	Market value of extra capacity	44%	70%
Inflows more unpredictable (fluctuate by 30%)	Hydro generation	100%	98%
	Gas generation	100%	112%
	Price	100%	100%
	Social Welfare	100%	100%
	Profit	99%	100%
	Social value of extra capacity	223%	158%
	Market value of extra capacity	174%	156%
Carbon tax \$25/t CO_2	Hydro generation	100%	100%
	Gas generation	90%	93%
	Price	112%	101%
	Social welfare	98%	99%

	Profit	109%	100%
	Social value of extra capacity	115%	114%
	Market value of extra capacity	112%	101%