**Water Scarcity, Market Power and Reservoir Management in Hydro Based Electricity Markets – Evidence from New Zealand**

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## Overview

## A number of electricity markets worldwide are characterized by a large market share of oligopolistic hydroelectric generators, a limited capacity of reservoirs to the store water for generation and highly seasonal patterns of inflows into reservoirs. Firms in these markets solve a dynamic problem: In each period there is a trade-off between, firstly, the revenue from generating using the water today and, secondly, the expected opportunity cost not being able to generate with that same water in the future. Because the future stock of water depends on decisions the firm makes today, the availability of water in these markets is an endogenous outcome. These stocks are especially important if market supply cannot meet demand when water is unable.

## When water is scarce, electricity prices will be higher for two reasons: firstly the opportunity cost of dispatching water is higher and secondly there is more market power since firms are facing more inelastic residual demand curves. However it is an open question as to how market power affects incentives of firms to manage their reservoirs between seasons, and thus the likelihood of such scarcity events occurring.

## The New Zealand Electricity Market (NZEM) is dominated by 4 oligopolistic firms. 55% of electricity supply comes from hydro-electric generation despite the fact it has highly seasonal inflows and only sufficient reservoir storage capacity to cover three months share of electricity demand. The NZEM experienced a series of electricity crises in 2001, 2003, 2006 and 2008 during which the country came within a few weeks of running out of sufficient water to guarantee of electricity supply. During this period spot market prices were extremely high and firms were accused of exercising excessive market power. In response to these repeated crises, the New Zealand government took actions in 2010 to curtail market power by reallocating hydro assets among firms and forcing them to sign electricity swaps.

## This paper assesses the strengths of these incentives to manage water and the impact of the reforms, It does using three approaches; firstly I use a theoretical model to highlight the incentives that oligopolistc firms have to manage water. Secondly market data is used to estimate implied opportunty cost of water based on firms’ past behaviour. Thirdly I simulate the dynamic cournot oligopoly problem firms in this market face and examines the impact that market power has on firms dispatch decisions and the equilibrium distribution of reservoir storage.

## Methods

Consider a simplified version of the problem faced by a profit-maximizing firm deciding how much hydroelectric generation to dispatch into a wholesale electricity market. The firm’s dynamic optimization problem is written below as Bellman equation where represents the discounted future profits of a firm with energy stored in their reservoir in week . The firm faces a residual demand curve net of all other generation, contractual obligations and competitior best responses, he discounts the next week’s profits at a rate and expects uncertain inflows into his reservoir of distributed on :

 (1)

When the maximum and minimum generation constraints are not binding, the firms problem has an interior solution and so the following first order condition holds:

 (2)

The right hand side of this equation represents the opportunity cost of consuming an additional unit of water which we shall call the ‘water value function’ . The firms implied assessment of this value at any point in time can be inferred by constructing the left hand side of this equation from NZEM bid and offer data. This data is used to trace out this ‘water value function’ and how it varies across weeks of the year, with reservoir level and with future inflows.

Since the ‘water value’ is an equilibrium outcome, the reduced form approach above is of limited value for policy analysis since it is unable speak to the effect of counterfactual policy changes. To estimate the impact of policy changes, a dynamic cournot model is used extending the simplified problem in equation (1) to account for multiple oligopolists who controlling both hydro and thermal assets bidding onto an electricity market.

## Results

Theory predicts that the opportunity cost of water should be decreasing in reservoir levels and increasing in future inflows. To test this in the data, the inferred ‘water values’ are regressed on the reservoir stocks of all firms, and their future inflows. There is a statistically significant negative relationship between ‘water values’ and both a firms own reservoir stock and those of its competitiors. There is a negative relationship between water values and inflows, however this relationship becomes insignificant once week-of-year fixed effects are accounted for. Further the relationship between the ‘Water values’ and reservoirs stocks is non-linear, an example is shown in Figure 1 below for the firm with the largest reservoirs.

Figure 1 Inferred 'Water value function' for Meridian Energy

The solution of our dynamic cournot model will give us the optimal policy function for each firm as a function of a firms own storage level , and his competitiors . Then given the expected distribution of inflows into reservoirs this can be mapped into an equilibrium distribution of reservoir levels . This allows us to infer the equilibrium distribution of electricity prices and probability of electricity shortage.

As previously noted, the policy interventions in 2010 aimed to reduce market power by reallocating hydro assets among firms and forcing them to sign electricity swaps. Our counterfactual simulations suggest these reforms succeeded at reducing market power in the sense that *conditional on reservoir levels* market prices are lower. However it also suggests that moves to mitigate market power have also *lowered the stationary distribution of reservoir levels*, increasing the risk of electricity shortages.

## Conclusions

Although it is impossible to say anything concrete without a full welfare analysis, the tradeoff implied in the simulations between market power, and the distribution of reservoir levels are worth dwelling on. Demand for electricity is realtively inelastic, which implies that although generator market power represents a transfer of wealth from buyers to sellers, the deadweight loss associated with market power is relatively small. On the other hand, the inefficiency arising from lost load outages is often much larger.

It is also worth noting that the issues discussed here are really only relevant in the medium term, they do not account for the role that high prices play in incentivising new investment. Indeed since 2010 there has been a large amount of new investment in geothermal and wind generation and there have been no recent sustained periods of low reservoir levels. However with the recent announcement of the closure of two of the largest thermal plants in the country, hydro is set to again to become more crucial to supply within the country and the issues raise in this paper might return to importance.

Finally water scarcity is also driven the constraints on the total storage capacity of hydro reservoirs. These constraints are in turn typically driven by environmental considerations. Indeed in New Zealand an infamous protest campaign of 1972 which limited the reservoir capacity of Manapouri, the country’s largest power station is seen as a key victory for the environmental movement. This model is able to speak to the costs of such environmental regulation.