WATER IS VALUABLE: the allocation of water and other resources in the New Zealand electricity market[1]

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This monograph investigates the role of the electricity market in the allocation of water and other resources used as inputs into electricity generation. We base our observations on the outputs of an original electricity spot market model designed to mimic the New Zealand electricity market. The model explains the role of water storage and the associated value of water in decision-making by generation companies. It also explains how water is allocated between on and off-peak periods and across seasons.

We explore the link between the spot and hedge markets, and examine how spot prices are translated into hedge and consumer prices. We then look at how various electricity infrastructure and climatic changes affect reservoir inflow characteristics, and the way these influence decision-making in the spot and hedge markets and thereby affect electricity prices. We discuss the social value of water in the electricity market and the wider economy.

1 Introduction

"If it weren't for electricity, we'd all be watching television by candlelight."

George Gobel, American comedian.

A world without electricity is unimaginable to most New Zealanders. Although not a necessity in the same way as food and shelter, electricity powers our lights, computers, phones and yes, our televisions. Yet despite the importance of electricity in our daily lives, many people would draw a blank if asked to describe how it comes into our homes and workplaces.

In New Zealand electricity is generated mostly from natural resources such as water, gas, geothermal heat, coal and wind. Hydropower makes up the bulk of production, providing 57.6% of all electricity generation in 2011.[3] However, water is a scarce resource and only one of several possible inputs into the electricity generation process. The question arises, therefore, as to whether water is being put to its most efficient use in electricity.

In this monograph we examine the role of the electricity market in the efficient allocation of water and other resources. We base our observations on the results of an original model of the spot market,[4] although the ambit of the monograph extends beyond the model. The monograph may

1 This paper draws on two strands of research conducted by ISCR under the MOTU project 'Integrated Research on the Economics of Climate Change Impacts, Adaptation and Mitigation', funded by the Foundation for Research Science and Technology. The monograph has benefitted from comments of Kevin Counsell and Richard Meade.

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3 Ministry of Economic Development (2012) *New Zealand Energy Data File: 2011 Calendar Year Edition*. Wellington: Ministry of Economic Development, at 104. Accessed at http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf.

4 Lewis Evans, Graeme Guthrie and Andrea Lu (2013) "The Role of Storage in a Competitive Electricity Market and the Effects of Climate Change", *Energy Economics* 36, at 405-418.

be viewed as adding to the work of Evans and Meade (2005), who described and appraised the New Zealand electricity market from 1985 to 2005.[5]

1.1 Resource allocation – how does it work?

The need to allocate resources efficiently is encapsulated in a well-worn but apt saying: "There is no such thing as a free lunch." In other words, resources are scarce relative to the countless uses to which they could be applied. A resource is efficiently allocated when it goes to its socially most highly valued use. This involves asking, among other things, what is this use, how much of the resource is used, and when the resource should be used. Where the resource is not initially owned by the person who will put it to its most efficient use, it may be traded until it moves to that person.

Commodities such as electricity are generally traded in complementary spot and hedge markets. The spot price is what the buyer pays for the commodity's immediate or near-immediate delivery. The hedge price is negotiated by contracting parties for the exchange of the commodity at points in the future. Since hedge contracts typically involve a fixed price and quantity they reduce risk and enable planning and investment. Nonetheless, spot markets perform a crucial gap-filling role: they enable mismatches between supply and demand of amounts hedged to be met by spot market trading, at the times the mismatches occur. Such mismatches are common in commodity markets, where supply and demand tend to be quite unpredictable. They can arise in the electricity context as hydro generators try to manage variations in water availability.

Electricity has unusual physical properties which differentiate it from other commodities. It is a homogenous good – when transmitted, it is impossible to determine which generator has supplied which quantity. Additionally, although its inputs such as water and gas are storable, it is not economically feasible to store electricity itself. This creates unique logistical issues since demand for electricity is continuous and supply must match demand at every instant in time. Fortunately, the electricity network and the smooth operation of the electricity hedge and spot markets ensure that you can watch all the Harry Potter films in a row, uninterrupted.

Because of electricity's physical traits, the relationship between electricity hedge and spot markets is a unique one. In many commodity markets, the commodity can be stored and this produces relationships between its hedge and spot prices. However, an electricity generator cannot store electricity for transmission at a later date if, for example, the current spot price is high but the hedge price is low. That said, there is still a relationship between the two prices. Spot price volatility incentivises signing up for hedges, but once hedged for a quantity of electricity, that quantity is essentially removed from the spot market.

The electricity spot price is determined by a multitude of factors, which include past and current water inflow levels, water storage, short term supply and demand[6] and transmission events. Market participants use hedge contracts to reduce future spot market risk,[7] and so the hedge price derives from expected spot price characteristics in the future. The hedge price reached today then affects the wholesale rates used to set consumer prices over the period of the hedge.

The electricity spot price is determined by a multitude of factors, which include past and current water inflow levels, water storage, short term supply and demand and transmission events.

Generators (sellers) and retailers (buyers) manage risk by entering into hedge contracts with each other. These fix the price for a quantity of electricity traded. Vertical integration (or gentailing) is another way to manage risk. It allows generators to trade internally between generation and retail arms, and then sell fixed price contracts directly to end consumers through the retail arm.

Generators are required to sell electricity in the New Zealand Electricity Market (NZEM), a wholesale spot market. Each trading period in the NZEM lasts half an hour. Given the volatility of the spot market and resultant hedge arrangements (which may be by contract or vertical integration), only around 20% of wholesale electricity transactions are carried out at the spot price. The remainder are priced at some hedge price.

1.2 Off to the electricity market

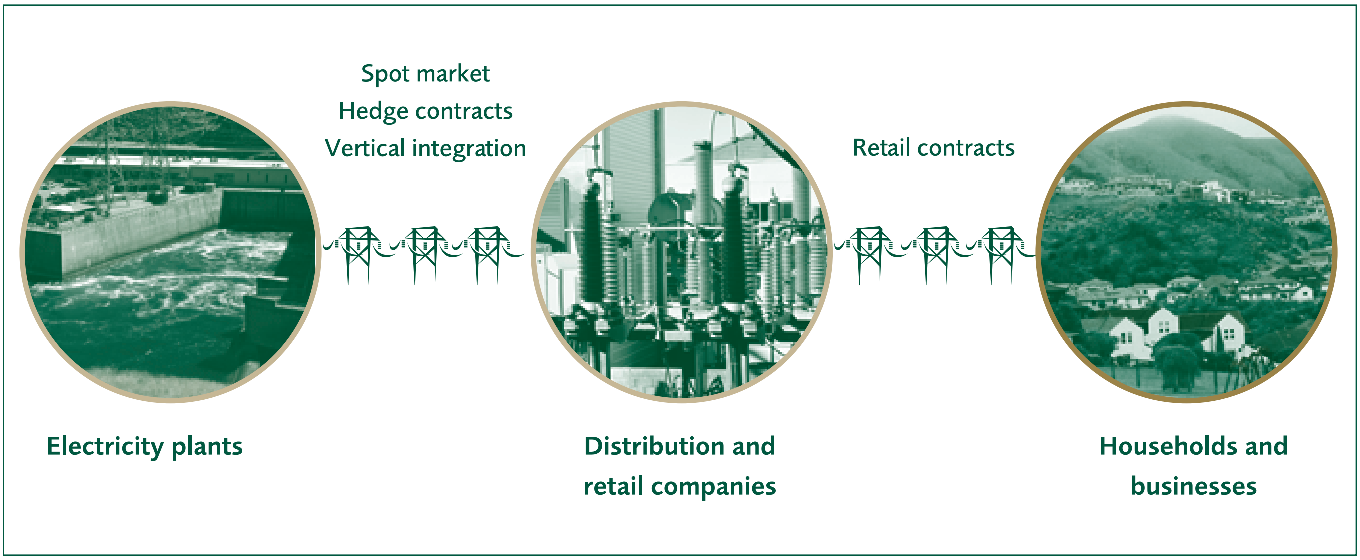
Our paper focuses on how different factors affect the allocation of water in the New Zealand electricity market. These factors include the

5 Lewis Evans and Richard Meade (2005) *Alternating Currents or Counter-Revolution? Contemporary Electricity Reform in New Zealand.* Wellington: Victoria University Press. Accessed at http:// www.iscr.org.nz/f310,8474/Alternating_Currents_e-book.pdf.

6 Daily temperature is a significant determinant of demand.

7 Hedge prices may be agreed for periods as long as ten years or as short as a day. Commonly in New Zealand, they last for three months.

Figure 1.1 From plant to end user[8]



availability of water storage, the price of water and state of the climate. To explore all of this, we require a working market model which mimics generator and demand decisions as observed in New Zealand.

Models are simplified representations of reality. An effective model is like a judicious gardener – it clears away extraneous detail to reveal what we care about. Many market participants use their own models to guide their bidding, offering and investment choices. We use a simplified model that encapsulates the efficient use of water storage, hydro and non-hydro generation and daily and seasonal patterns of demand. Our model allows for climate change through variation in the water inflows that are the inputs into the hydro generation process. This allows our model to show credibly how climate change affects electricity spot prices.

Before introducing our market model, we first examine the concept of water inflows. Second, we then examine the model and the outcomes it produces. Third, we explore how climate change may affect generation policies and what this means for both the spot and hedge markets. Fourth, we discuss the allocation of water in the wider New Zealand economy. Finally, we draw some conclusions from our observations.

8 This figure omits the trading platform (i.e. the transmission grid) and the few large industrial users that purchase directly from generators or run their own generation. These users are not the focus of this paper.

2 Inflows: now and in the future

In New Zealand electricity generation begins with nature. Nature affects both demand and supply of electricity. On the supply side, nature provides inputs into the generation process by rain, snowmelt, rivers and lakes, natural gas, wind and so forth. On the demand side, changing temperatures guide our use of electricity-consuming appliances such as heaters and air conditioners. This monograph concentrates on changes to the supply-side effects of nature.

New Zealand is comparatively abundant in rainfall and natural water resources. However, these are unevenly distributed throughout the country. For example, the Cleddau Valley near Milford Sound is one of the wettest places in the world, with approximately 13.4 metres of average annual rainfall.[9] In comparison, the interior valleys of Central Otago see less than 600 millimetres of annual rainfall.[10] Rainfall also varies greatly not only between regions, but over time – both seasonally and over the years.[11]

Hydro generators use water as their renewable 'fuel' and are subject to all of its natural variations. It is beneficial for generators to manage this variation, and they do so through water storage. The fluctuating availability of water affects generators' decisions to offer to generate electricity in the spot market, and the resultant spot electricity price.

The term 'inflow' refers to water that flows into hydro reservoirs. Inflows fluctuate in the short-term and vary with factors such as the level of rain or snowmelt, but they do follow general seasonal trends: they are generally highest during early summer when the winter snow melts. Conversely, demand for electricity tends to peak in winter as the nation collectively braves the cold.[12]

The discrepancy between electricity demand and inflow levels gives rise to the all-important question for hydro-generators: should I run water through the dynamos today, or store it away for use tomorrow?[13] Since river flows are continuous, generators face this question in each half-hour trading period. Where inflows are not immediately used in generation, they can be stored in hydro lakes (reservoirs) until needed. Reservoirs have

The Clyde River dam in summer – store or run?[14]

9 NIWA (20 December 2011) "New Zealand's rain falls mainly in the mountains", NIWA. Accessed 12 March 2013 at http://www.niwa.co.nz/news/new-zealand%E2%80%99s-rain-falls-mainly-in-the-mountains.

10 Matt McGlone (13 July 2012) "Ecoregions – Central Otago" Te Ara – the Encyclopaedia of New Zealand. Accessed 12 March 2013 at http://www.teara.govt.nz/en/ecoregions/page-8 =.

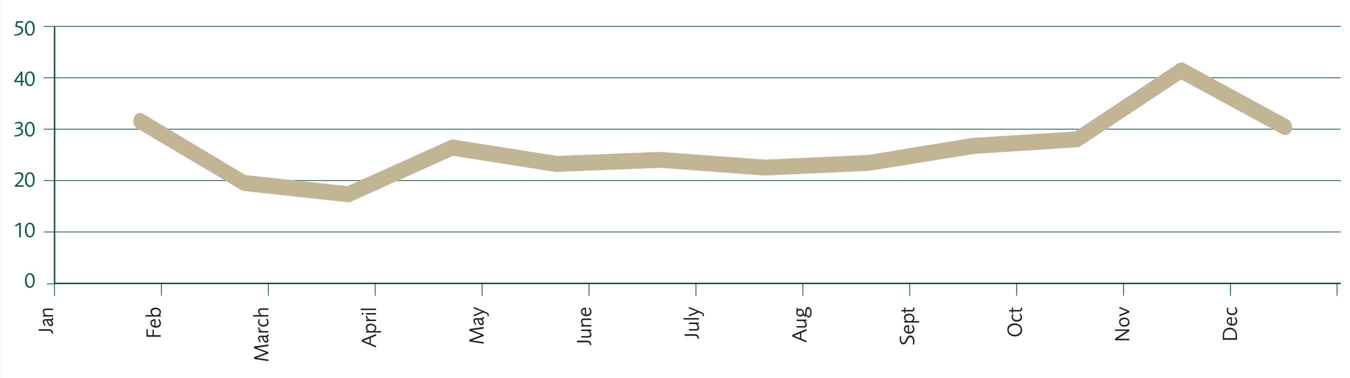
11 Rainfall may vary over the years due to systematic climate fluctuations such as El Niño and La Niña. See: Reid Basher, Brett Mullan, Jim Renwick and David Wratt, "El Niño and Climate Forecasting," NIWA. Accessed 12 March 2013 at http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/elnino.

12 That said, there is increasing demand in summer for air conditioning.

13 The generator also has the option of spilling inflows, but this is not commonly exercised.

14 Photo taken in December 2012.

Figure 2.1 Monthly inflows in 2006



only a very small potential effect on the annual amount of water available for hydro generation. Nonetheless, they fulfil the key function of shifting the availability of water between time periods, which we delve into later.

2.1 Predicting inflows

Hydro generators predict future inflow levels to guide their decisions on whether to store or generate. This affects their offering decisions in the markets and hence has implications for electricity prices, the generation policies of non-hydro generators and social welfare (i.e. good economic performance). To aid prediction, hydro generators look to both past and current inflow levels.

Inflows may be measured either in the short or long term. Short-term inflows may relate to periods as short as a single trading period. They are most relevant in the spot market, which reflects characteristics of inflows in the very short term. Long term inflows, on the other hand, relate to a window of time in the distant future (e.g. a year). They provide information about the performance expected of the spot market in the distant future and consequently are more relevant for hedge pricing.[15]

Different time periods call for different approaches to prediction. The further a market participant wants to forecast into the future, the less useful immediate past inflow figures are. For example, if someone wanted to forecast October 2014 inflows, knowledge of June 2013 inflows would provide no assistance. However, the latter figure would be of assistance in forecasting July 2013 inflows. Having said that, seasonal patterns assist in forecasting each season's inflows in the short and long term, and hence knowledge of October 2013 inflows would be of some help in forecasting October 2014 inflows.

2.2 Inflows in the near future

In the short term, inflows are related over time and, while they fluctuate, they follow a general pattern. Unusually high or low inflows eventually return to average levels. With this in mind generators are able to predict with a modicum of confidence inflow levels in the near future. Generators are also aware of four other key pieces of information useful in making generation decisions: the season, the state of the electricity market, past inflows and prices, current inflows and the level of water storage.

If long term inflows are thought of as a cake, then short term inflows are the slices. Figure 2.1 above illustrates such a slice of time.

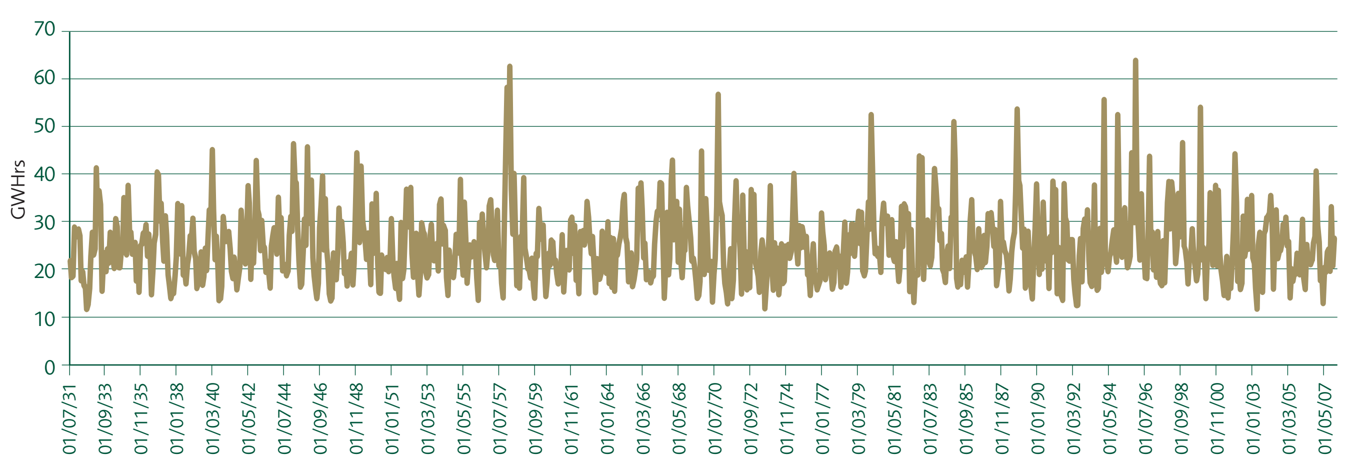
Let us take the case of a manager of a hydro plant. It is early March, and inflow levels are remarkably low for the time of year. Is it better to conserve water rather than generate electricity? Not necessarily, because stored water is available. Furthermore, the manager is aware of the general pattern of inflows over time, and that inflow levels are likely to rise and return to their norm within the next month or so. The manager will choose to run water through the dynamos today, knowing it is probable that the reservoirs will later be replenished.

The story ends well, as she offers to supply a greater quantity of electricity at any given price to the spot market than would otherwise be the case. Other hydro generators, having similar information and being in the same position, respond in a like manner.[16] This has a downward

15 However, long term pricing does not affect the short term.

16 The state of water storage, climate and demand across the country are well known by market participants at points in time, although other factors, such as the supply and price of gas, may not be. Some generators may be in a different storage position and make different choices.

Figure 2.2 Monthly Flows 1931 – 2006 (GWHrs) Average = 25.00



effect on the spot price, and leads us to the lesson of the story – inflow predictions in the short term are a determinant of the spot price.

2.3 Inflows in the distant future

… inflows are a product of nature, and climate change has the power to alter both the long and short term characteristics of inflows …

The aim of predicting inflows over the long term is to assess the level and variation of the future spot price in order to inform long term pricing, such as those negotiated in hedge contracts. Generators and retailers enter long term contracts with the object of risk management – that is, to protect themselves from fluctuating prices in the spot market. Expected future spot prices are therefore one determinant of long term prices (and by extension, the retail prices charged to end consumers).

Long term predictions are not assisted by knowledge of past and current inflow characteristics, as described earlier, although seasonal patterns are useful. This is because unusual short term inflows tend to return to their average levels. Inflows during the distant future are independent of one another; rain today suggests rain tomorrow, but says little about rain in a year's time.

Figure 2.2 illustrates inflow levels over more than seventy years. In hedge pricing, parties will take the prices associated with the average level of inflows over the long term, adjusted for the season and for demand patterns. Those who are considering entry into a hedge contract are primarily interested in a 'safe' price over the life of the contract, not day-to-day shifts in prices resulting from recent inflow levels and other factors. Generators want higher contractual prices while retailers want lower ones, and they bargain with each other until a mutually acceptable price is reached.[17]

The importance of inflow predictions and forward-looking behaviour cannot be underestimated. The expected level of future inflows affects how generators make offering decisions today. As touched on earlier, inflows are a product of nature, and climate change has the power to alter both the long and short term characteristics of inflows – and hence future spot prices and hedge prices that are agreed upon today.

With an understanding of inflows and how hydro generators operate, we can now turn to consider the spot market.

17 The demand, supply and terms of long term hedges will be affected by participants' expectations of the level and variation of future spot prices, which are in turn affected by the characteristics of inflows and other market characteristics.

3 The spot market

Our model encapsulates a competitive New Zealand electricity spot market. The model is set in continuous time, since rivers flow continuously and the supply of electricity must equal demand at each instant in time. We have calibrated our model to the 2007 New Zealand electricity market.[18]

Importantly, our model has a forward looking approach. It recognises that generators face risk and uncertainty in the future, and use past and current information to reduce this risk and assist generation decision-making.

We will first look at different elements of the model, including how the NZEM functions and particular aspects of hydro and non-hydro generation, before examining the model as a whole. Once we are familiar with the model, we will indicate how we use it to predict how generators respond to different situations, including the availability of hydro storage, the relaxation of capacity constraints and climate change. The choices that generators make affect electricity prices and quantities, the composition of fuels used in generation, and the price of water.

The New Zealand Electricity Market (NZEM) functions as a gross (or compulsory) spot market, overseen by a central operator.[19] In every trading period each generator and retailer effectively provides the operator with its supply or demand curve. The operator pools the curves together to derive total demand and supply, from which a market clearing price[20] and quantity are obtained.

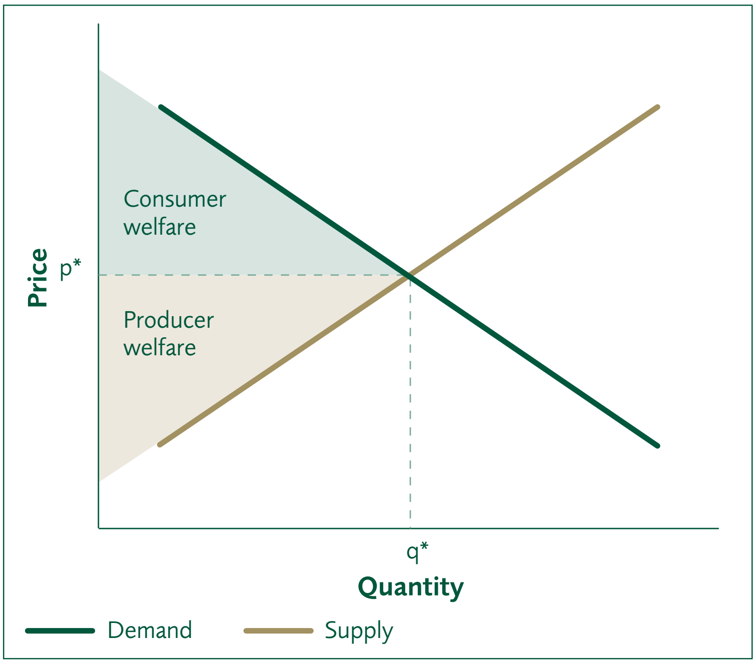
3.1 The generic market model

The generic economic market model is an abstract representation of any market. It is useful to aid discussion of the model framework and key assumptions before incorporating more realistic, explicit and necessarily complicating features. Figure 3.1 below depicts the market for each trading period:

A (total or market) supply curve details how much of a commodity producers will supply at different prices.[21] The (total or market) demand curve gives the quantity demanded by consumers. Where the curves intersect, quantity demand equals quantity supplied (q*). In continuously operating spot markets such as that for electricity, such market clearance occurs at each instant in time.

The entire shaded area gives the total welfare (or as economists call it, surplus) that results from market clearance. Producer welfare is the benefit to producers of having received a higher price than what they would have accepted. A producer at the bottom of the curve still receives p*. Consumer welfare, in the same vein, is the benefit

Figure 3.1 Generic commodity market



18 The 2007 processes give us the marginal cost curves that we will shortly encounter. We have an equation that estimates the process by which inflows evolve over time, allowing us to predict inflows in each period.

19 All generators are required to offer physical flows of electricity into the gross pool. They are free to enter financial hedge contracts with any party.

20 In fact, there is a market-clearing price at each of approximately 250 nodes (markets). Where there is one market, the price levels across these nodes (i.e. regions) vary together. This was found to be the case for NZEM at least up to 2008 (Lewis Evans, Graeme Guthrie and Steen Videbeck (2007), "Assessing the Integration of Electricity Markets using Principal Component Analysis: Network and Market Structure Effects", *Contemporary Economic Policy* 26(1), at 144-161).

21 We shall see below the specific shape of the electricity supply curve.

to consumers of having paid less than what they were willing to for the commodity. The total sum of producer and consumer welfare is the measure of efficiency: the price level at p* maximises efficiency at that point in time.

Producer welfare benefits fall on the various parties and determines the rents of scarce resources. In the case of electricity in New Zealand, much of the producer welfare is reflected in the value of water in each trading period. The welfare is mostly held by the government, as owner of hydro generators and tax collector in general.

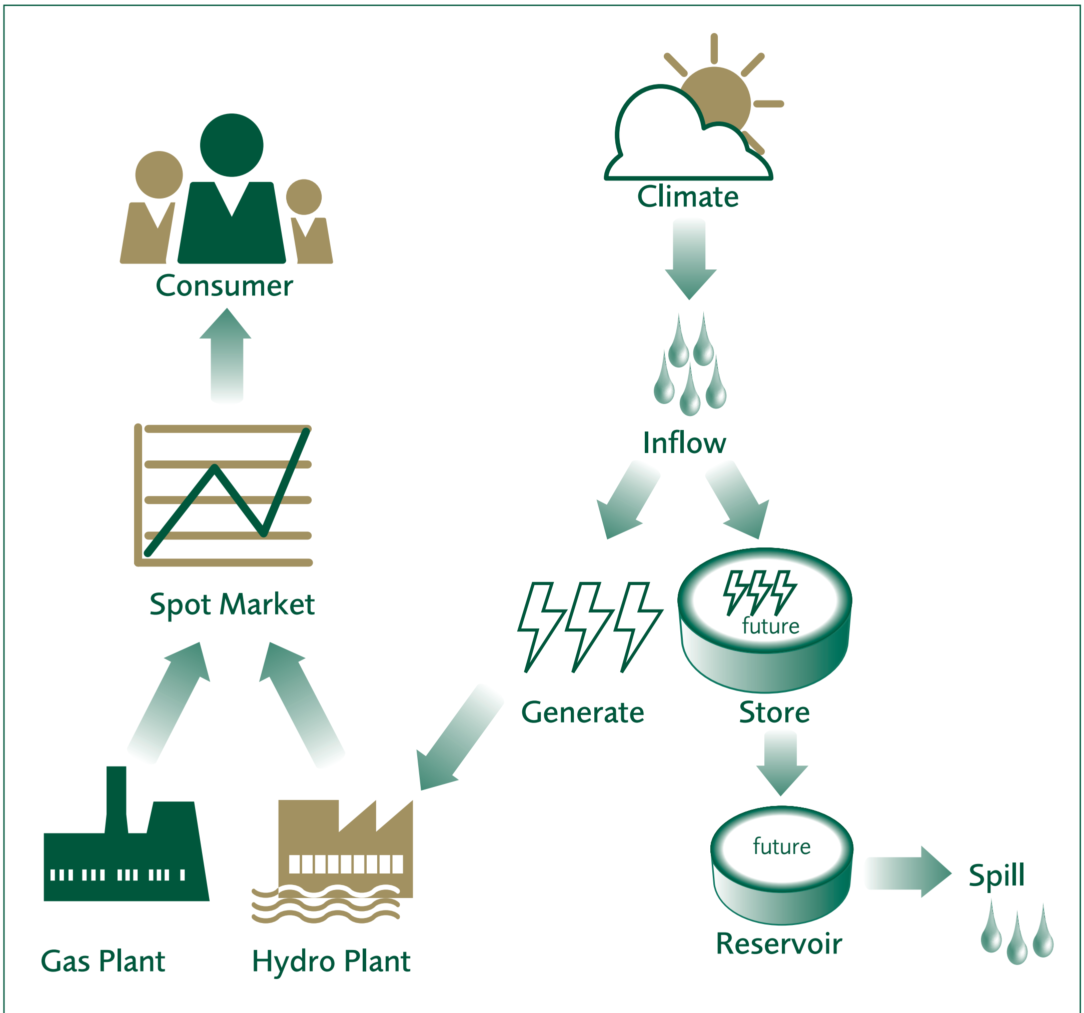
This generic model captures the heart of any market, but does not explain the idiosyncrasies of the NZEM which make it so remarkable. As in the generic model of Figure 3.1, which assumes perfect competition,[22] all generators who 'bid' to produce in a given trading period receive the same price. The market uses up the cheapest generation first, and then sets the price at p*, the marginal cost of the most expensive plant used (the marginal decision-making plant).

We focus on the supply side of NZEM. This is essentially a multi-competitor world, as encapsulated in Figure 3.2, with competition among and between hydro and non-hydro gas generators. Our model uses gas as a label for all non-hydro generation. Although electricity can be generated in a variety of ways, the label is useful since it is typically a gas plant that is the marginal[23] decision-making plant, and gas substitutes for hydro generation.

We are interested in the outcomes reached in a workably competitive market, but for simplicity our model is solved as if by a social planner to approximate this outcome. In the case of a workably competitive market, generators are each able to make their own generation choices. This is a result mimicked by the social planner.[24] The planner approach is computationally simpler in a model.

The social planner's problem follows: it must decide how much hydro and gas generation to operate, given its objective of maximising welfare

Figure 3.2 Climate to consumer: the market model

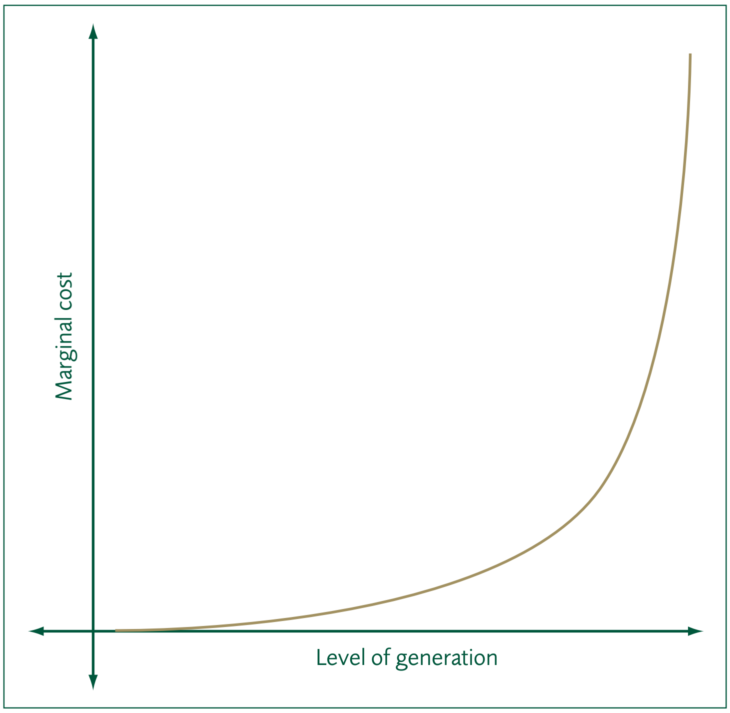


22 A perfectly competitive market is one with many small competitors, who are price takers. In fact, all electricity markets are oligopolies and New Zealand is no different. If the market is workably competitive (the practical representation of a competitive market), it will yield efficient outcomes. There are various definitions of a workably competitive market. This includes one where there may be some monopolistic competition, but with sufficient competition to preclude monopolistic abuse of market participants.

23 Marginality is a concept readily encountered in daily life, and refers to the next unit of a thing. Suppose you were forced to eat tiramisu. 'Forced' may be the wrong word when you are eating the first couple of slices, but probably appropriate by the time you get to the fifth slice. The marginal benefit of eating tiramisu is decreasing; each extra slice yields you less utility.

24 Competitive generators choosing their own generation policies while striving to maximise profits in a workably competitive market produce, approximately, the market outcomes the social planner would choose. To read more about this, see: Evans and Meade (2005) *op. cit.*

Figure 3.3 The marginal cost of gas generation



into the foreseeable future.[25] To choose the optimal policy the social planner must acknowledge that all generators face cost and capacity constraints. Both gas and hydro generators are limited in plant capacity. Hydro generators may shift production between time periods by storing inflows for later production, though storage capacity and actual level of inflows place limitations on this inter-temporal substitution.

Hydro and gas generators also face different cost structures. In our model there will always be some gas generation because we assume that gas plants are situated closer to consumers, so the cost of electricity transmission is cheaper for gas generators than for hydro. Although the balance between demand and supply in the North and South islands is constantly changing, most hydro plants are located in the South Island,[26] whereas the bulk of electricity demand comes from the North.

We assume that hydro generators benefit from zero running or reservoir costs. Alternatively, these are fixed costs and do not vary with the level of generation. We assume fixed storage capacity in our model; and it takes the infrastructure of the market as given. There is no investment in either new or existing plants or reservoirs. The model can, however, tell us how to value more or less investment that relaxes these constraints.[27]

In the electricity market marginal cost curves function as supply curves. This is because each generator's spot market offers are affected by the offers of other generators, and so each has an incentive to offer in at the lowest possible price (i.e. the marginal cost).[28] It is therefore worth going into the different marginal cost structures faced by hydro and gas generators in more depth.

3.2 The marginal cost of gas

Gas generators face increasing marginal costs of operation, as not all gas generation plants are equally efficient. The marginal cost of gas generation for an individual generator depends not only on the price of gas, but also how efficient that particular plant is. Aggregating individual marginal costs gives us a total marginal cost curve which looks something like Figure 3.3.[29] The very steep part of the graph occurs where the market gas generation reaches capacity. There can be no more gas generation, no matter what the price.

The industry marginal cost curve is basically the supply curve – gas generators will not generate at a price any lower than the marginal cost of production at any given quantity. As more gas generation takes place, more relatively inefficient plants are used, raising the marginal cost of generation.[30] This is because higher cost

25 The foresight of the market (social planner) is a source of dynamic efficiency that includes per-period efficiency assessed over time into the foreseeable future.

26 South Island reservoirs alone contain about 85% of New Zealand's total hydro storage capacity. Transpower "Hydro Generation" Transpower: System Operator. Accessed 12 March 2013 at http://www.systemoperator.co.nz/hydro-status.

27 Investment in infrastructure is an important component of dynamic efficiency, which is achieved by efficient outcomes over the long run. Dynamic efficiency is to be contrasted with static efficiency, a more short-sighted approach which does not account for investment, innovation, education and so on.

28 In fact, in a workably competitive market it is expected that offers will be close rather than equal to marginal cost. Offers to generate are affected by risk and hedges, as we shall discuss later.

29 The supply curve of the model is for all non-hydro generation. It is termed 'gas marginal cost' because gas generation is discretionary and competes with hydro directly at the margin. Base load plants (e.g. geothermal and wind generation) do not.

generators are used in production only after all low cost gas generation has been exhausted. The flattened part of the curve captures these low cost plants, which include base load generation and peak efficiency plants.[31]

3.3 The marginal cost of water

The marginal cost of water is vital to answering the hydro generator's store water or run generation question. Also known as the shadow price of water, it comprises the opportunity cost of using a unit of stored water immediately, and thereby forsaking future use. For both the social planner and profit-maximising generators, at their generation levels there is no difference between the marginal value of water in generation today and in the future (which necessarily is an expected, rather than actual, value).

In the planner's case, if a difference exists then social welfare is not being maximised. The planner will therefore choose to create welfare by changing the amount of electricity generated today. In the independent generator's case, a difference in the value of water between today and tomorrow means that it is not maximising profits. Suppose that the payoff of generation today exceeds the shadow price of stored water. Generators will choose to generate more in the present, raising the value of water today relative to the expected future value of water planned for use tomorrow: generation today will occur until the two values are equal. That is, the shadow price of water changes so that the opportunity cost of use today is the same as the value of use in the future.

Like the electricity spot price, the shadow price of water changes with the time of year, inflow levels and water storage levels. Unlike the spot price, it is not a figure that can simply be looked up. We calculate the shadow price using 200 years of simulated daily data.[32] The shadow price is determined by all characteristics of the electricity system, including inflows and demand.

The graphs in Figure 3.4 show the level of the shadow price depending on the season and the proportion of stored water to storage capacity. The upper curve on each graph depicts the shadow price where inflows are very low, and the lower curve for very high inflows.[33] When storage levels are low, the gap between high and low inflows is narrower in spring and summer than autumn and especially winter. This is because inflows become very valuable when water is scarce but demand is high.

The shadow price tends to rise during winter and autumn, when inflows are low but demand is high. It tends to be lower during spring and summer, when the reverse is true. In spring and summer, stored water is less valuable, as it is likely to be replaced before winter season. The shadow price may even reach zero when inflow levels are especially high and reservoirs are at full capacity. In these situations hydro generators may run the water simply because there is too much of it. Alternatively, they may spill it, although this rarely occurs.

To illustrate, suppose that it is a dry year: inflows and water storage levels are low. Hydro generators are uncertain whether they can replenish reservoirs in the near future. Consequently, the shadow price of water soars and hydro generators will respond by cutting back production and eking out stored water. In

30 Recall that gas includes base load plants such as geothermal and wind that, in most situations, run independently of the spot price.

31 Base load generators include variable (e.g. wind) and must-run plants (e.g. geothermal), which have very low operating costs. Peak efficiency plants are those that are efficient to run during periods of high demand, but not year-round. An example is an existing coal-fired plant; since the generator has already sunk costs into building the plant, it may as well be used. It would, however, be inefficient to build a new coal-fired plant because of the associated high fixed costs.

32 The model is calibrated to the 2007 New Zealand electricity market. The simulations are derived from a process that explains inflows, which is estimated from inflow levels between July 1931 and June 2008.

33 The upper curve shows the situation for inflows at the 2.5th percentile of the unconditional distribution of y; these are extremely low inflows. The lower curve is for inflows at the 97.5th percentile, for extremely high inflows.

Figure 3.4 The shadow price of water

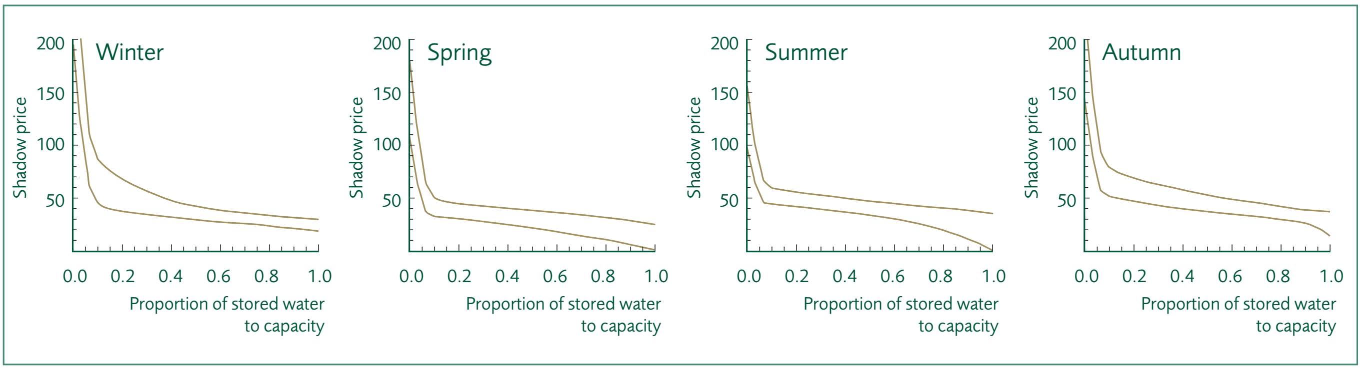
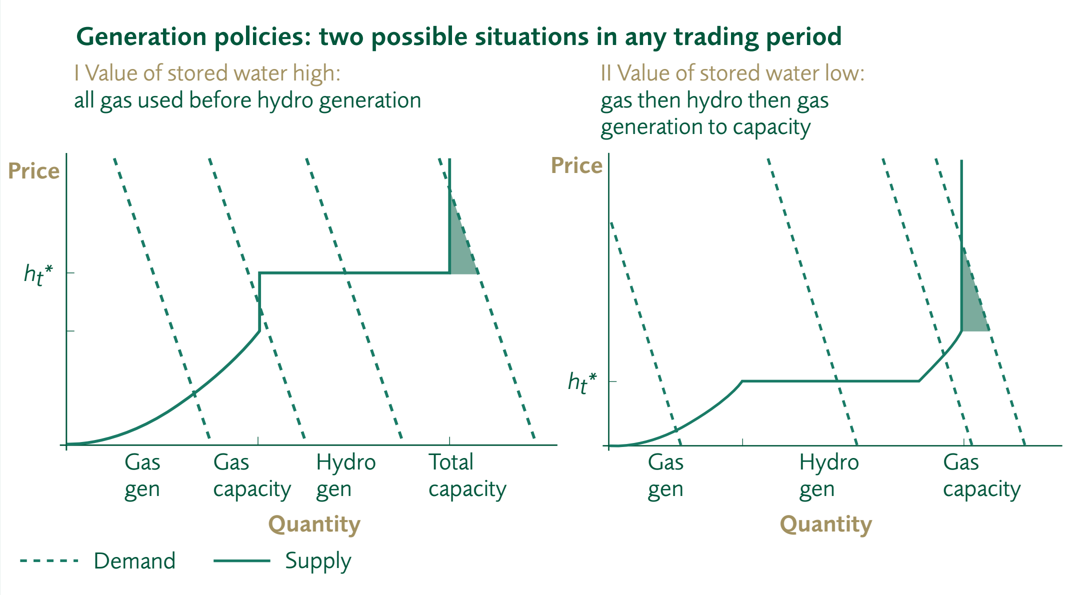


Figure 3.5 New Zealand electricity market



such a case the expected value of using stored water in the future becomes very high, and a high return is required to incentivise generation in the current period. Electricity prices rise as a result. Gas generation goes some way to closing the gap left by reduced high generation, but it, too, becomes more expensive as less efficient plants are called into production.

We therefore see that the expected value of future generation (both gas and hydro) plays an important role in setting electricity prices today. This value depends on interest rates,[34] all aspects of the electricity market, the elasticity of demand, generation policies and expected inflows. Our model builds in the expectations that embody these features. Being more conversant with the limitations faced by hydro and gas generators, we will now turn to the model proper.

3.4 This little generator goes to the spot market

Our generic market model captures the essence of the NZEM, although the supply curve does not look quite the same. The two graphs (Figure 3.5) show what the market looks like at different water price levels and for different demands (depicted by the broken lines). In the first graph, the shadow price of water (h_t*) is higher than the marginal cost of the least efficient gas plant. Hence gas generation occurs to its maximum level before hydro comes into play. In the second graph, it is lower. As we can see, the level of the shadow price has a significant effect on the supply of electricity and the market price reached.

The total supply curve is the amalgamation of gas and hydro marginal cost curves, and represents the least-cost way of producing electricity at various quantities. The curious shape of the supply curve reflects the different cost structures of hydro and gas generators. The 'curved' part of the curve represents gas generators' increasing marginal costs, whereas the horizontal part indicates hydro generation – the spot price does not change across this part, as it does not cost extra for more hydropower to be produced up to capacity.[35] Finally, full capacity is denoted by the vertical part of the curve.

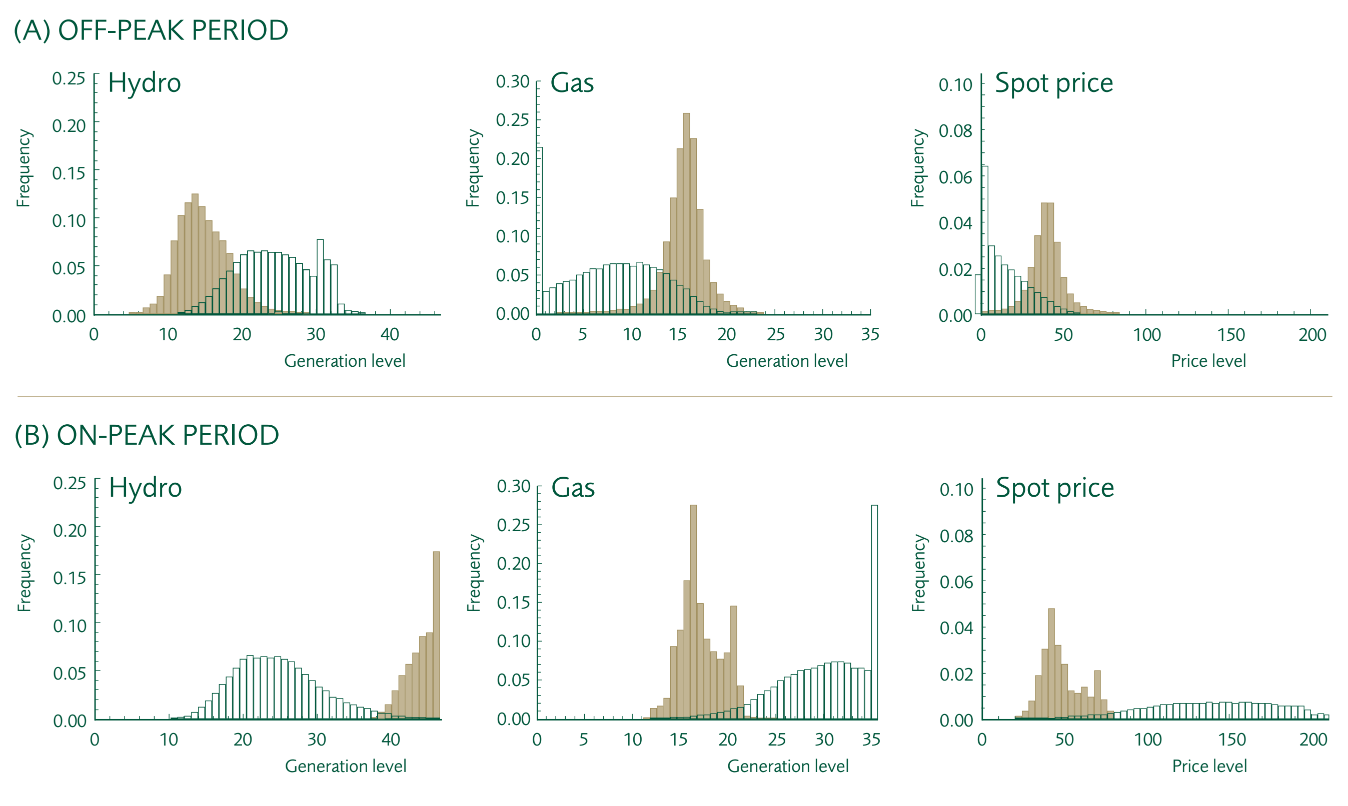
The exact position of the hydro generation part of the supply curve depends on the shadow price of water. The shadow price affects the pattern of generation across different levels of demand. Although it is not strictly correct to have one supply curve to more than one demand curve, and vice versa, we do so for illustrative purposes here. In these graphs, the further to the right a demand curve is, the higher demand is at all levels of generation. The right-most curve, for example, may arise from daily peaks.

At such high levels of demand, electricity is already being produced at capacity. Some users are ready to pay a high spot price for the electricity, beyond what any generator would have accepted to generate. All generators are paid the same spot price and receive 'rent' (excess returns which, in

34 Interest rates matter where time is involved. Any income you choose to spend today could have been put into bonds, term deposits or other financial instruments.

35 In fact, these diagrams are a convenient approximate description. They depict equilibrium outcomes, since generally the supply curve for electricity cannot be depicted independently of the demand curve. To see this, consider the third demand curve in the left diagram. If this demand increased, there would be more hydro generation in the trading period. The only way extra generation can occur today is if the value of stored water falls: thus the shadow price of water is affected by demand. The flat segment will generally not be flat.

Figure 3.6 Within-day electricity spot market



the short run, cannot induce more generation).[36] This creates a loss of consumer welfare, indicated by the shaded triangle (as compared to more supply available at the price indicated by the horizontal part of the triangle).[37]

Suppose the winter is harsh and electricity demand is very high. How does the level of the shadow price of water affect generation patterns? When the shadow price is higher than the marginal cost of the least efficient gas plant (as in Figure 3.5's first graph), demand and storage are such that hydro generators require a relatively high spot price in order to generate. Gas generation will occur up to capacity, whereupon the spot price leaps to match the shadow price if any hydro generation is to occur to meet remaining demand.

When the shadow price is lower than the marginal cost of the least efficient gas plant, gas generation pushes the spot price up until it is equal to the shadow price. At this point, hydro generation comes in and occurs up to capacity. If demand is still not satisfied at hydro capacity, the less efficient gas plants operate to provide for the remainder.

3.5 Generation patterns over time

Generators care about daily and seasonal generation. Demand varies according to predictable patterns over the courses of a day and a year, influencing how gas and water resources are allocated. We want to compare generation in the daily and seasonal markets, and how this varies depending on whether or not water storage is available. For simplicity we use the terms run-of-river world[38] (no storage) and reservoir world (storage available). It is essential to note that demand does not change with the availability of storage facilities.

High inflow periods do not necessarily coincide with high demand periods, so water storage is essential to the efficient allocation of water resources in the electricity market. Reservoirs allow hydro generators to divert high inflows into high demand periods, producing socially optimal outcomes.[39] It also enables the efficient substitution of gas and water between the different timeframes (also known as inter-temporal fuel substitution).

3.5.1 The daily spot market

Daily generation is split into on-peak (high demand) and off-peak (low demand) periods.

36 In the short run, supply is fixed and generators cannot 'magic' up more electricity. However, if the rent phenomenon occurs repeatedly, this may induce plant investment in the long run, increasing capacity. Such infrastructure investment can be valued but is not a decision feature of our model.

37 The loss only occurs where demand is sufficiently high, and increases as demand increases. Where it does occur, it is very low at the 2007-calibrated reservoir capacity

38 So-called where hydro generators run river flows through the dynamos as they come.

39 We know this to be the case since the model is set up to solve the social planner's welfare-maximising problem.

Waking up in the morning, popping some bread in the toaster and switching on the kettle for tea contributes to on-peak demand. Off-peak periods occur at times like two in the morning, when most people are asleep.

Figure 3.6 indicates how gas and hydro generation is distributed over the course of a day. The darker parts of the graphs depict the reservoir world and the lighter parts depict the run-of-river world.

The vertical axis on each histogram gives the frequency of results obtained from the simulated 200 years. The horizontal axes on the hydro and gas graphs give the respective levels of generation, while on the spot price graphs they give the load-weighted price level.[40] For example, in the first (off-peak) hydro graph, the level of generation with storage available was 10 units about 4% of the time; without storage 10 units were hardly ever generated.

For comparative purposes, it is simplest to begin with the run-of-river world. In this world, hydro generation levels stay fairly constant over on- and off-peak periods, as the inflow levels that dictate generation tend to change little over a day. Gas generation levels, on the other hand, pick up significantly during on-peak periods. This is necessary to meet the heightened demand. As gas generation rises, more high cost plants are put into production and consequentially the spot price rises.

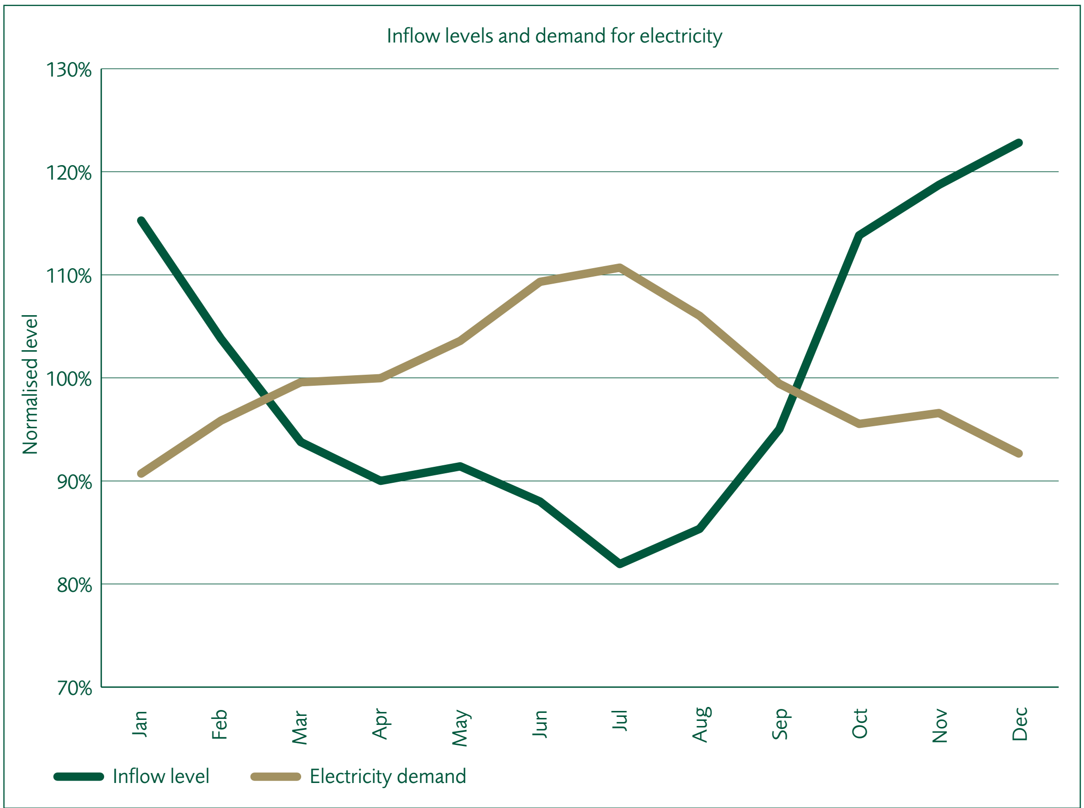
Increased high cost gas generation raises the on-peak spot price. Since it is the highest cost plant that is the price setter, the spot price is also subject to changes associated with the inflow level on a particular day. Where there is a severe drought, gas generation must be expanded.

The introduction of reservoirs changes generation distribution dramatically. Off-peak hydro generation falls while on-peak generation rises, as hydro generators are able and prefer to store water for the high demand period. Low-cost gas generation replaces hydro generation in the low demand period, pushing the off-peak spot price up. Hydro generation supplants high-cost gas generation in the high demand period, which pushes the on-peak spot price down.

Essentially, the availability of storage enables the redistribution of water over time.[41] This enhances welfare and results in a lower *average* spot price, which varies little through the course of the day. The off-peak price is higher, while the on-peak price is lower, than in the run-of-river world.

Waking up in the morning, popping some bread in the toaster and switching on the kettle for tea contributes to on-peak demand. Off-peak periods occur … when most people are asleep.

Figure 3.7 The hydro generator's mismatch problem[42]

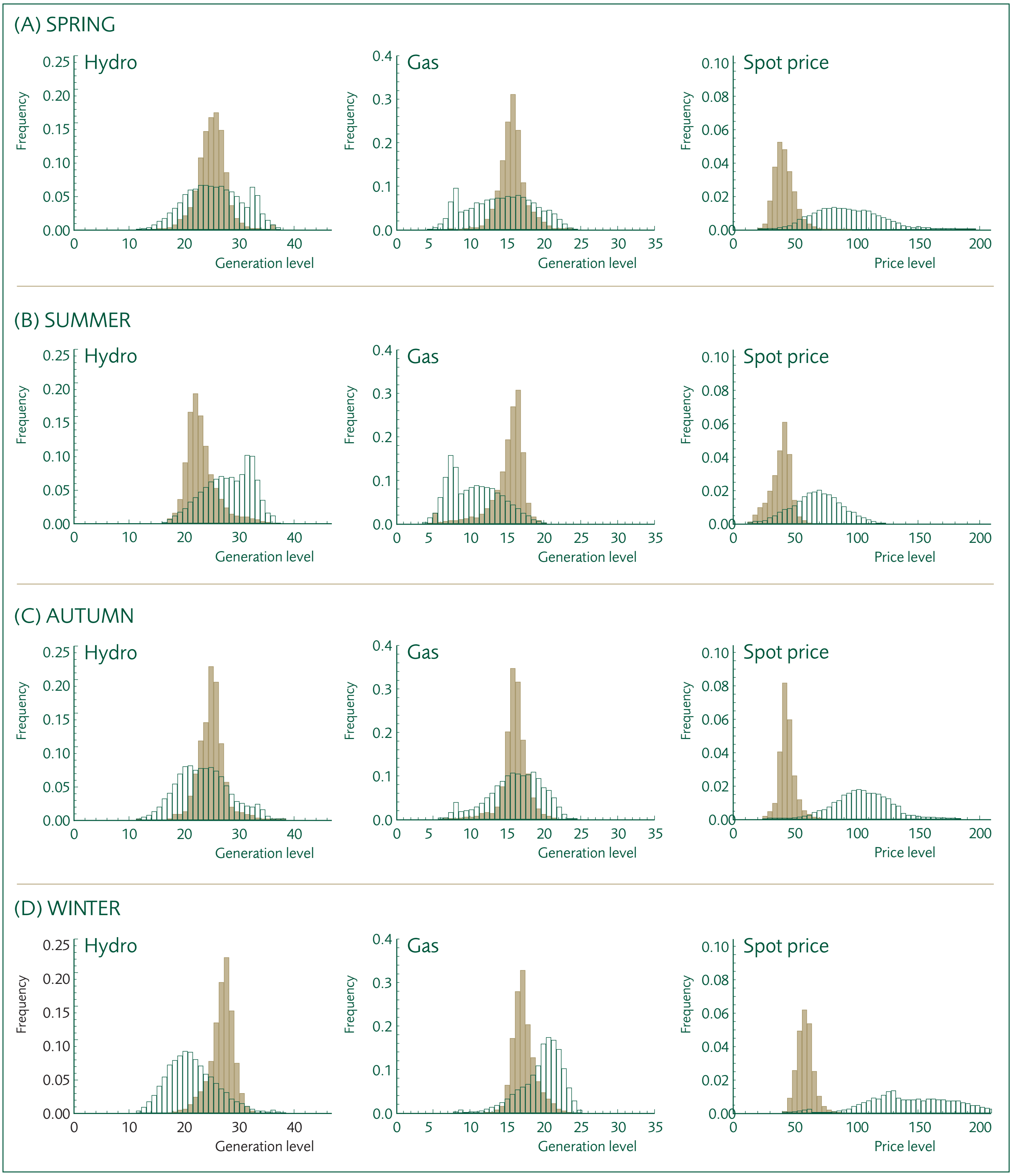


40 Spot prices are accorded different weights according to trade volume at that time of day. For example, the spot price at 2 am has a lesser weight than that at 5 pm because less electricity is being exchanged.

41 There is also an issue in the timing of the use of stored and contracted gas that our model does not consider.

42 The data in the graph is normalised. Actual figures for demand and inflow levels have been divided over the average. This shows the percentage by which the figures deviate from the average level. For example, in July inflow levels are typically at 81% of the average level.

Figure 3.8 Inter-season electricity spot market



3.5.2 The seasonal spot market

The seasonal market is slightly more complex than the daily one, because inflow levels vary across seasons. This creates a mismatch problem for the hydro generator, as illustrated in Figure 3.7.

Demand for electricity peaks in winter and is at its lowest in summer,[43] whereas the opposite is true for inflow levels (that is, the inputs into supply). The availability of sufficient water storage solves the mismatch problem, as it allows hydro generators to run inflows and supply electricity in sync with demand levels.

Figure 3.8 tells us about seasonal generation. Again, the shaded parts refer to a world with

43 Summer demand has been on the rise as more people use air conditioners. However, New Zealand's summer electricity use is still low relative to other countries.

storage, and the light parts to a run-of-river world.

We begin again with a run-of-river world. Hydro generation reaches higher levels in spring and summer, consistent with high seasonal inflows. In contrast, winter and autumn hydro generation is low. As in the daily market, where less hydro generation occurs, there is more gas generation, and vice versa. The no-storage spot price shifts dramatically across seasons. Once again, inflow variation creates considerable variation in the price. When inflow levels are especially low, increasingly inefficient gas plants are called to operate, driving up the spot price.

When storage facilities come into the picture, hydro generators reduce summer production to store away inflows for winter use. In a reservoir world, summer hydro generation rarely reaches full capacity even during daily on-peak period.[44] When winter rolls around, hydro generators operate at or near full-capacity during on-peak periods, unless storage levels are very low. The graphs show that hydro generation distribution in any given season is more concentrated. With reduced fluctuation in hydro generation levels, there is much less inter-season variation in the spot price.

As is the case with daily operation, storage facilities enable a competitive electricity market to trade increased low-cost gas generation during low demand periods for decreased high-cost gas generation during high demand periods. The only difference is that the timescale involved in seasonal generation is larger. Both daily and seasonally hydro reservoirs influence the spot market to enable greatly improved efficiency outcomes for the electricity market.

3.5.3 Volatile prices

The 200 years of simulation produces spot market price volatility similar to that of NZEM. The volatility is apparent from the spread of prices in the daily and seasonal diagrams. The price volatility comes about because demand within trading periods is relatively unresponsive to trading period price, and there are various climatic and other factors that affect demand and supply within a trading period. We have also seen that variation in inflows feeds through the shadow price of stored water to spot prices of electricity.

We have not yet considered the welfare (equivalently efficiency) effects of volatility per se. These are squarely relevant to hedging arrangements which we consider below in section 3.6. The variations of market infrastructure and climate change considered in this section and in section 4 all affect the volatility of prices; sometimes quite dramatically.

3.6 Infrastructure change: relaxing constraints

So far we have looked at how the shadow price of water affects water allocation between 'today' and 'tomorrow', and how the availability of storage facilities affects allocation within a day and throughout the year. Now we ask how allocation changes if we relax some of the constraints faced by generators: namely, reservoir capacity, hydro generation capacity and the level of base load generation.

3.6.1 Increase in reservoir capacity

At first blush, increased storage capacity seems like good news for both producers and consumers. The actual result may be surprising. An expansion in reservoir capacity has little effect on within-day prices, but a significant effect on seasonal prices. Since inflow levels remain fairly constant through the course of a day, a small amount of capacity sufficiently facilitates daily fuel substitution.[45] On the other hand, far more capacity is required to transfer large amounts of water from summer to winter.

A larger reservoir capacity also lowers the average cost of meeting demand by increasing the ability of hydro generators to shift water between time periods. This increases consumer welfare overall, but because the spot market produces a uniform-price, producer welfare falls. The lowered cost of production translates to a lower market-clearing price. All operating generators sell at the new lower price, but the amount of electricity being produced does not change.

Here is the surprise: generators benefit from the use of high-cost gas plants during high demand periods, for the spot price is set at these higher marginal costs. This applies to all hydro and infra-

… generators benefit from the use of high-cost gas plants during high demand periods, for the spot price is set at these higher marginal costs.

44 The only situation where summer hydro generation runs at full capacity is where storage facilities are full and inflows are unusually high – in which case generators may as well run the water through the dynamos.

45 The electricity market model assumes that the shadow price of water remains constant within a day.

marginal gas producers because of the unit-price auction feature of the NZEM. Thus an increase in reservoir capacity is detrimental to generators, since it reduces the use of the highest-cost plants, lowering their average profit flow. On the other hand, this is more than offset by an increase in average welfare flows to consumers, leading to a rise in total welfare.

3.6.2 Increase in hydro capacity

Hydro generators often run close to full capacity in winter. An expansion in hydro capacity enables increased hydro generation in winter. Although this causes the average summer spot price to rise because of inter-seasonal substitution, this is more than offset by a lower average winter spot price.

Overall, increased hydro capacity increases consumer welfare at the expense of producers, since a lower average spot price applies across the board for generators. The net effect is a minor rise in total welfare.

3.6.3 Increase in base load generation

Suppose that more base-load and efficient peaking plants were added into the mix.[46] With more low cost gas generation units in the market, the average level of water storage falls considerably. There is much less inter-season fuel substitution, as hydro generation is used less as a gas substitute in winter. The benefits of substituting increased low-cost gas generation in summer for decreased high-cost gas generation in winter decline, because gas plants are more homogeneous.

Producer welfare increases, as there is no change to the level of spot prices, but more electricity is being produced. Consumer welfare actually falls a small amount. There is a widened spread between average summer and winter spot prices, so the reduced inter-season fuel substitution raises the profits of both hydro and infra-marginal gas generation, leaving consumers worse off. Total welfare rises.

46 This has the effect of moving out the total marginal cost curve; that is, the cost of gas generation falls for each level of output.

4 Climate change and the spot market

Climate change is one of the key issues that have dominated political discourse in recent years. In the context of hydro generation climate change can affect inflow variance, average levels (mean) and the speed at which they return to the norm (reversion). All of this has implications for generator behaviour, spot prices and social welfare. We examine how potential climate change may affect electricity prices through consideration of five key scenarios, as follows.

4.1 Reduction in average inflows

Imagine that New Zealand is becoming more arid and reservoirs are receiving lower average inflows.[47] This will ease storage system pressure (since storage capacity is usually reached in winter), and hence inter-temporal fuel substitution increases. There is a greater spread between winter/summer and on/off-peak generation in hydro generation, and a decreased spread in gas.[48] Two things will happen to the electricity spot price: the gap between seasonal prices falls while the average price rises.

Since hydro generators have less 'fuel' to produce with, high cost gas generation increases. This pushes up the average spot price through the use of extra, less efficient plants. Hydro and infra-marginal gas generators benefit from the increased spot price to the significant detriment of consumers. Overall, there is a substantial decrease in total welfare.

4.2 Weaker seasonal variation

New Zealand already has a comparatively temperate climate, but in this scenario we take seasonal variation a step further. Inflows are subject to weaker variation – the difference is less marked between average summer and winter inflows. With reduced variation, hydro generators store less summer inflows, and inter-season fuel substitution falls. Any potential increase in storage capacity becomes less valuable.

There is greater spread between daily on- and off-peak hydro generation and a smaller gas spread. Conversely, there is decreased inter-seasonal hydro spread, because of increased winter inflows. Total welfare changes little: there is only a small increase in consumer welfare, and a small decrease in producer welfare for hydro generators.

4.3 Reduction in predictability of inflows

When inflow levels become more unpredictable the ability of generators to plan for the future is compromised. Increased short run volatility leads to increased long run variability. However, to isolate the effects of the former, in this scenario we reduce inflow predictability without varying average inflows, i.e. yearly supply of water does not change.

Volatile inflow levels create greater potential for very large inflows. This places pressure on the market's ability to store water and increases the value of extra storage capacity.[49] Less inter-temporal fuel substitution occurs. Within a day there is a larger spread between on- and off-peak hydro production. Inter-seasonally, there is a smaller spread, because of increased winter inflows. The opposite is true in each case for gas. Overall, the result is a minor increase in consumer welfare, and a minor decrease in hydro welfare – netting out to negligible change in total welfare.

4.4 Increase in mean reversion rate

We know that in the short-term unusual inflow levels return to the norm. The mean reversion rate refers to how quickly this takes place. In a changed scenario, we combine an increased mean reversion rate with decreased inflow predictability, so that in the long run inflow variance is unaffected.

An increased mean reversion rate reduces the use of water storage and significantly reduces inter-temporal fuel substitution. There is only a minor change in the value of expanded storage capacity. On a daily basis there is less spread between on- and off-peak hydro generation levels. Seasonally speaking, the spread is larger. In both cases the opposite is true for gas generation levels. There is little change in total welfare, as a small increase in consumer welfare and a small

47 In fact, NIWA suggests a likely future for New Zealand in which inflows increase as a result of climate change. The effect of this can be inferred from our results of a decrease in average inflows. See: "Climate Change Projections for New Zealand" NIWA. Accessed at https://www.niwa.co.nz/sites/default/files/ipcc_04_nz.pdf.

48 The spread is the difference between the average values of two periods. For instance, where the average level of generation is 100 units in winter and 120 in summer, the spread is 20.

49 It is less so if we also increase the mean reversion rate, which we examine in the next scenario.

decrease in producer welfare work against each other.

4.5 Introduction of a carbon tax

In 2005 the Fifth Labour Government mooted a carbon tax as a way of controlling carbon emissions in New Zealand and as a response to climate change and global warming. Although an official carbon tax was never enacted, our current Emissions Trading Scheme (ETS) is an analogous scheme. The ETS effectively fixes the price of carbon, but does not constrain generators in how much carbon they produce – they are able to purchase carbon credits as required.

In the context of the electricity market, a carbon tax or ETS targets gas generators by increasing the marginal cost of gas generation. This decreases the level of gas generation at any given price. Meanwhile, there is little or no extra hydro generation to pick up the slack, since the effect of the tax is to increase the shadow price of water. Average hydro generation does not change very much, but is less used in winter. This raises the post-tax price of electricity, reducing consumer welfare. On the other hand, producer welfare rises, due to the uniform-price auction effect. The overall effect is a drop in total welfare.

Climate change is a tricky beast, and we have visited only a few of the possible changes that it could induce (or in the case of carbon tax, effectively has induced). Although in some cases climate change increases producer welfare, we assume that generators and retailers are risk-averse and are concerned about decreases as well – they prefer to keep profits relatively stable over time rather than experiencing great ups and downs. Gentailing, or vertical integration of retail and generation, is one way to achieve this goal, cutting out the go-between that is the spot market. Another method is to take out hedge contracts, so it is to the hedge market we will now turn.

5 The hedge market[50]

The hedge market is both alternative and complementary to the spot market. While all physical flows of electricity go through the spot market, financial flows encompassing the price paid for electricity also take place in the hedge market. Together, the two markets produce wholesale electricity prices and the retail prices charged to final consumers. In this section, we look at how inflows and all the other factors guiding spot price offering decisions affect participation in the hedge market.

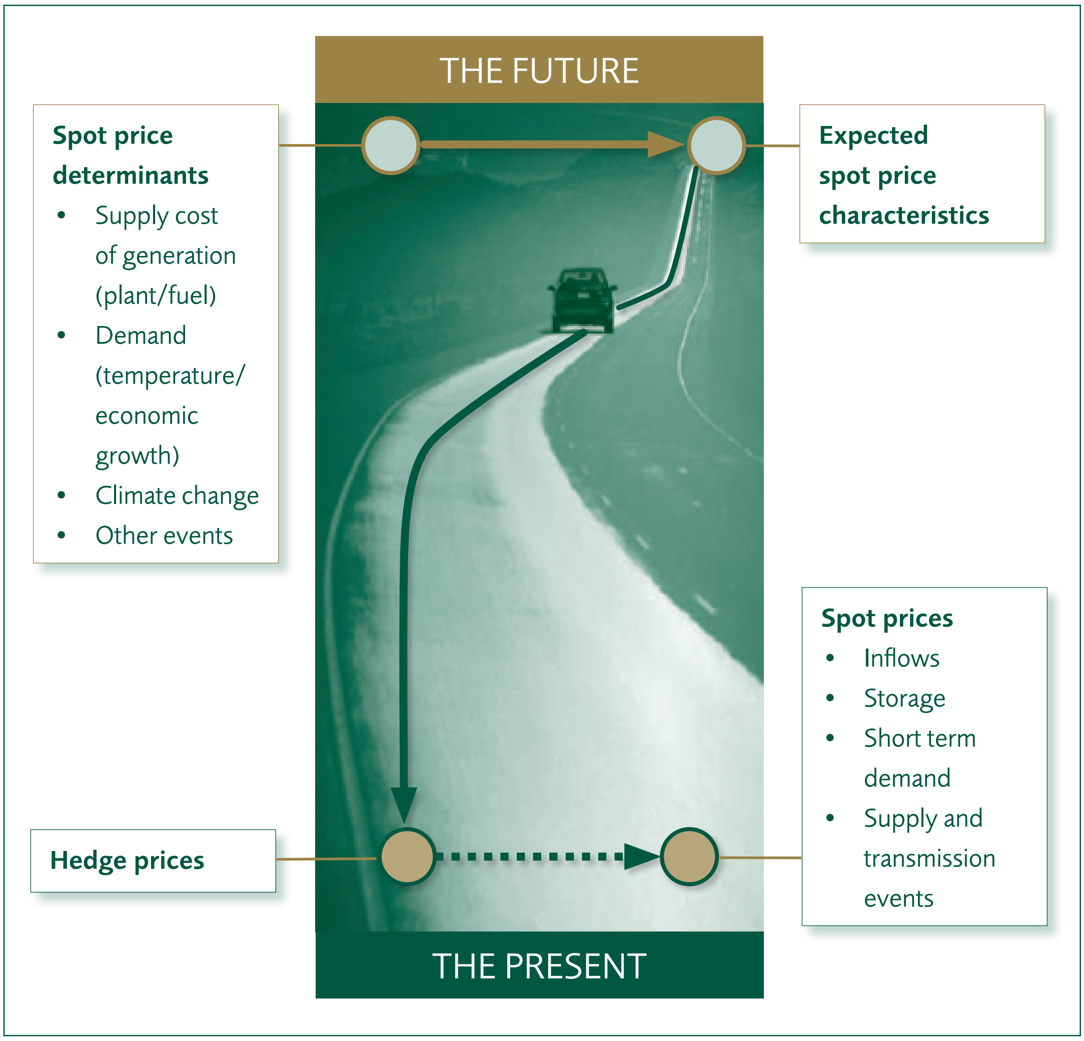
Our analysis of the hedge market is underpinned by some key assumptions. We treat long term financial contracts for the exchange of electricity as hedge arrangements that fix the electricity price for certain periods of time and certain quantities of electricity. We take hedges between retailers and generators as having a similar effect to vertical integration between them.

We attribute the demand and supply of hedges to be driven by volatility in the spot price – both its short term volatility and its future volatility and likely general level in the long term. We treat generators and retailers as though they are risk averse and use hedges to mitigate the volatility of prices received for generated energy. [51]

5.1 The spot-hedge link

Figure 5.1 elaborates the relationship between the markets. Generators and retailers agree upon hedge prices today to protect themselves from spot price fluctuations over some future period, whether that is for the next few months, or a year or more. Therefore, all the characteristics that determine future spot prices have bearing on today's hedge prices. Participants can also use past and current information to form expectations about the level and variation of future spot prices,

Figure 5.1 Hedging into the future



50 This section draws on Chapter 6 of Gabriel Godofredo Fiuza de Braganca (2011) "Essays on the interaction between risk and market structure in electricity markets". PhD Thesis, Victoria University of Wellington; as well as Evans, Guthrie and Lu *op. cit.*

51 It is commonly assumed that while individuals are risk averse, firms can be taken to be risk neutral because their (risk averse) owners can diversify (i.e. manage their own risk). Even if firms had a neutral attitude to risk, they still may wish to manage risk by hedging (e.g. to avoid costs of bankruptcy). Further, there may be other strategic reasons for hedging. We assume that risk aversion on the part of generators and retailers is their reason for entering hedge contracts.

as discussed in the context of water inflows earlier.

Prospective spot prices clearly affect hedge arrangements. What is less obvious is that existing hedge arrangements affect today's spot prices to some extent. A hedge arrangement for 100 Megawatt Hours (MWh) for each trading period for 2013, for example, effectively removes 100MWh from the spot market pricing process.[52] This will alter offers and bids in the electricity market and thereby affect prices.[53]

New Zealand generators are required by law to place all their offers of physical generation into the spot market, but they are free to enter bilateral hedge contracts. The electricity hedge contract is a purely financial arrangement. A hedge contract is about future delivery of the commodity, but the generator cannot store the required electricity in a barrel until the time comes. Nor can it point to a particular quantity of electricity running through the network the following month and say to the buyer, "There you go, I produced that for you." Instead retailers and generators use hedges to fix the price of electricity for an amount actually transmitted through the spot market.

It is particularly important for retailers to hedge, since they hold retail contracts with households and businesses. These contracts specify a particular price that must be held for a period of time, over which the spot market price could change markedly. Retailers will hedge the amount of electricity demanded by end consumers, or else risk purchasing wholesale electricity at a high spot price and selling it on at a lower contracted price. Take the example of the short-lived retailer On Energy, which launched and delisted in the same year. The company failed to hedge sufficiently before an especially dry winter and was subject to extremely high spot prices.[54] By August 2001, it had exited the retail sector and sold off its 418,000 strong customer base to its competitors.[55]

A common type of hedge contract in the electricity market is the contract for differences (CFD).[56] Parties to a CFD agree on an electricity strike price. If the spot price differs from the strike price, one party pays the other the difference. If the strike price averages out to be the same as the spot price over the life of the contract, no party ends up profiting at the expense of the other. Vertical integration of generation and retail, producing gentailers, is a hedging arrangement with similar effects, where a strike price is a price internal to the gentailer.

5.2 Modelling the spot and hedge relationship

In modelling the relationship between the spot and hedge markets, we assume a lack of complete markets. This term refers to the situation where there is a competitive market for every good and service. In relation to financial markets, this would mean that there are contracts to insure against all possible adverse events. This inevitably does not play out very well in the real world. It would take a superhuman to write a complete contract—not to mention such a contract would cover events as outlandish as intergalactic warfare or the kidnap of all plant employees.

We make the common presumption that market participants are risk averse. They want to achieve a balance in minimising exposure to the risks of the spot market, while maximising profits. There being no complete insurance contracts, hedging is a way to mitigate risk.

The timeline (Figure 5.2) illustrates the decision-making processes of generators (sellers) and retailers (buyers) in hedging. These decisions are guided by forward-looking expectations of future markets, as well as current and past information. Spot market decisions are made every half hour, with the hedge market settled well in advance of spot market participation. A participant can be on different points of the timeline at once. For instance, a generator may be making a hedging decision based on a future spot market, while making an offer into a present spot market.

At midday on January the 31st, our arbitrary start point, generators decide on a desirable list of hedge amounts and prices they would be prepared to supply at, while retailers decide on a schedule for what they would like. The overarching goal of any participant is to manage its risk in a way that maximises its expected utility of future profit. This last phrase is like an oversized cookie – it is a mouthful but can be broken into bits quite easily. Expectation, or anticipation, is essential since

52 Ignoring volatility and transmission costs, the generator would generate 100MWh (or 200MWh for a single half-hour trading period) and be unconcerned about the spot price for this amount of electricity.

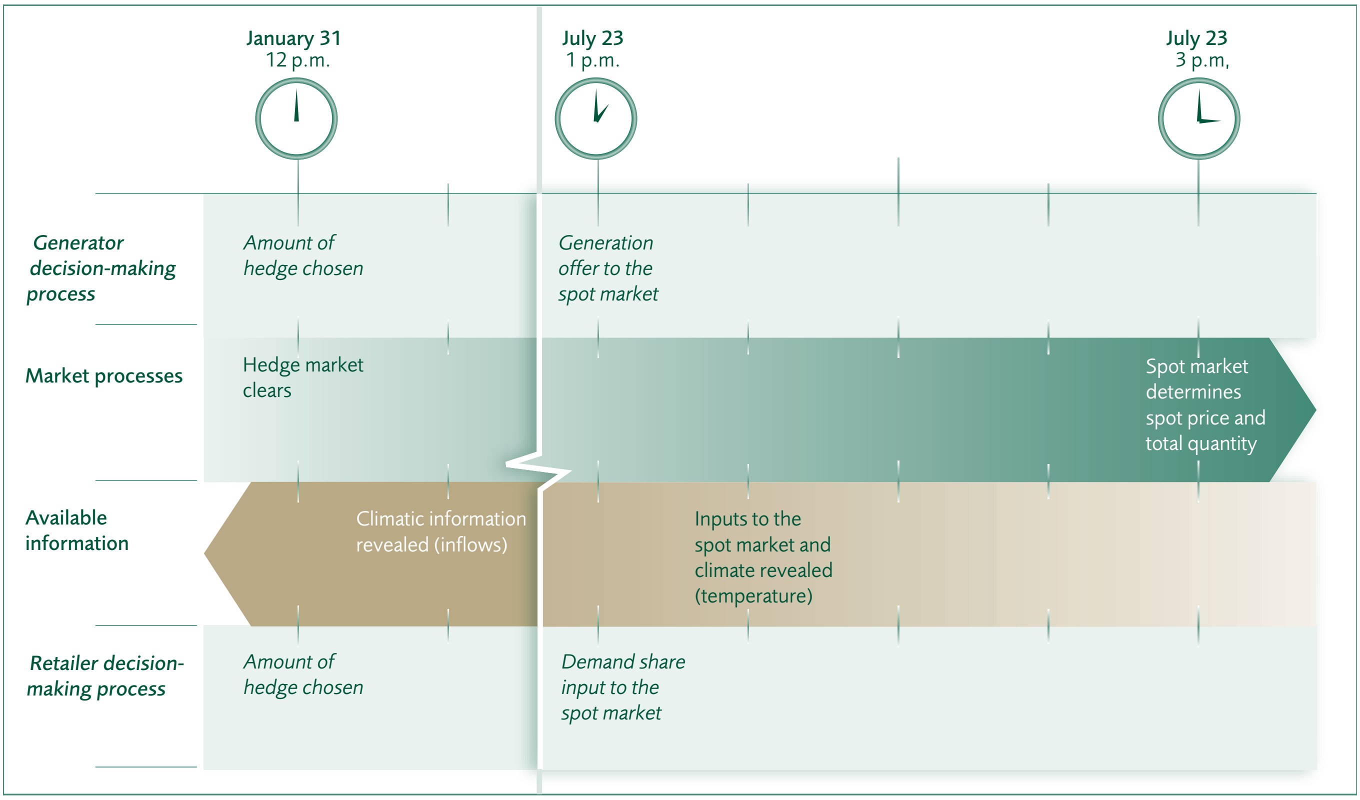
53 In fact, it will be the aggregate effect of widespread hedges in a competitive market that affects the spot price.

54 Paul Nillesen (2008) *The Future of Electricity Distribution Regulation: Lessons from International Experience.* The Netherlands, Ridderkerk: Ridderprint, at 149-150.

55 New Zealand Herald (18 October 2001) "On Energy to delist today", New Zealand Herald http://www.nzherald.co.nz.

56 Here is an example. The generator Angry Inflows contracts to sell 100MWh in a trading period to Positive Energy by means of a hedge called a contract for differences (CFD). Angry Inflows and Positive Energy agree to a strike price of $50 per MWh. If the spot price is $70, Angry Inflows gets $70 from the gross pool but has to rebate the $20 difference to Positive Energy. If the spot price is $30, Angry Inflows gets $30 from the pool and $20 from Positive Energy (who paid $30 to the pool). This way, the price per MWh is held at $50 no matter the spot price. In the relevant future half hour trading periods, Angry Inflows offers in the spot market 200MWh for a price low enough to guarantee generation. Angry Inflows is guaranteed the contract price for 100MWh, but must ensure that the electricity gets transmitted. For generation volumes over 200MWh, Angry Inflows will receive the spot price for the additional generation. For generation amounts less than 200MWh in a trading period, it will have to purchase the balance from the spot market to fulfil the CFD.

Figure 5.2 Hedge markets in action



participants are looking at future possibilities. 'Utility' indicates that market participants are taken to care about risk: in particular, they are risk averse rather than risk neutral.

The hedge supply and demand schedules result from market participant expectations about the future spot market and their reasoning back to 31 January accordingly.[57] The quantity and price of hedges demanded or supplied depends on a number of factors: how risk averse the participant is, the spot market share it enjoys,[58] and the mean and volatility of future spot prices. When all participants have made their hedging schedules trading occurs and the hedge market clears setting the market quantities and strike prices for hedges.

The next step in time reveals supply-side information – less esoterically, inflows gush into reservoirs. Generators learn how much they can produce, and from the hedging positions they have chosen, they have also decided what prices they are willing to accept before they do so. Existing hedges decrease the interest that generators have in the spot market. Generators will offer in at a low spot price to ensure that they will be selected for generation and will meet their hedging volume (which they receive the strike price for). Beyond that volume, supply may require a spot price which is different from the strike price.

Next, participants discover information relevant to electricity demand. In the short term, this is the temperature. Once the demand-side information is revealed, retailers will then demand the amount of electricity as required by their retail contracts.[59]

Once generators and retailers have made their respective spot market decisions, the central operator collates the supply and demand curves and determines a market-clearing electricity spot price and quantity. Recall that the market price is the one that is received by all operating generators for all units of generation used. The spot market clears, and the next trading period begins.

The whole point of engaging in the hedge market, as stressed, is to manage risk. The risk takes two forms: one is the level of the future spot price, while the other is the volatility of the spot price in the future. Both are risks for decisions taken today: be they about hedging, or supply or demand related investments in the electricity market.

The 'available information' timeline shows that climate is an important area of risk. After all, electricity supply draws on natural resources which are inherently volatile. Participants will

57 This means that all the factors that affect the spot price will affect hedges (and prices charged to retail consumers). These factors include: water inflow characteristics, demand, storage capabilities, input prices, characteristics of hydro and non-hydro generation, and so forth.

58 Retailers with a large share of the spot market have particular cause to hedge. There is a trade-off for generators: reduced risk from hedging comes with reduced spot market power (if any existed) because the hedged amount is essentially removed from the spot market.

59 In our model, the retailers have a given share of market.

therefore, where possible, wait for climatic information to become available, to better guide their decision-making.

What happens when the information involves great disruption? We explored the implications of inflow volatility in the spot market and upon social welfare earlier. Given that the spot and hedge markets are inseparable, knowledge or even fear of potential disruption leads participants to take out long term contracts in the hedge market. It is the effects of climate change on the hedge market that we will now turn to explore.

6 Climate change and the hedge market

We have established that climate change affects electricity spot market price levels and indicated that it also affects spot-price volatility. Climate change will also affect hedge prices and quantities. In this section we show the effect of the climate changes we have studied on hedge prices taking quantity as fixed.

Evaluating the climate effect is complicated for three key reasons: two markets are involved (the spot and hedge markets), each market has at least two classes of participants (generators and retailers), and prices and quantities in each market are affected by climate conditions. In this case the hedge market is of particular interest. To simplify matters we focus on the hedge price and recognise that increased spot price volatility will increase the supply and demand for hedges since retailers and generators are both risk averse. This increase in supply and demand produces an ambiguous effect on the market price and quantities of hedges, but for our analysis we assume the demand effect outweighs the supply effect and so an increase in volatility increases the price of hedges.[60] We also assume that an increase in the future average, or expected, spot prices will increase the strike prices of hedges (CFDs). These changes are important as they feed into consumer prices and tariffs.

Assuming that hedges span trading periods so as to be long run (e.g. they are not merely a day ahead), then climate change affects hedge prices and quantities through its impact on expected spot levels and variation in the distant future. We consider the four now-familiar climate change-induced scenarios.[61]

The second and third columns of Figure 6.1 show how the spot price changes with each scenario. In some cases, there is significant change in the level and volatility of the spot price. The right column shows the change in hedge prices for a given quantity of hedges, after market participants adjust their expectations of future spot markets. Here, the hedge price is the same as the strike price in CFDs.[62]

Suppose a retailer expects the spot price to rise tomorrow. She will also expect that the supplier (generator) will insist on a higher strike price. If the spot price is expected to be more volatile in the future the demand and supply of hedges will increase at the same strike price. As mentioned, Figure 6.1 assumes that the demand relative to supply effect of increased volatility dominates and so an increase in volatility results in a higher price of hedges.

A fall in average inflows leads to a dramatic rise in the expected spot price, which will be reflected in hedge strike prices. However, there is also a significant fall in volatility, which lowers hedge demand relative to supply. The effect on the hedge market is ambiguous. Secondly, weakened

60 We also assume no change in the quantity of hedges in the hedge market-trading outcome. Hence the welfare of generators and retailers depends upon the effects of climate change on hedge prices.

61 While we do not consider these here, it is possible to explore the effect of investment in electricity market structure on hedge prices.

62 If the strike price of a CFD equals its expected spot price, the CFD has no forward looking riskless profit to either the seller or the buyer. Hence expected spot price levels are an important determinant of the strike price.

Figure 6.1 Climate change scenarios

	Expected spot price	Spot price volatility	Hedge price
25% fall in average inflows	+ 49%	- 21%	?
25% weaker seasonality in inflows	- 1%	- 2%	↓
Reduced predictability of inflows	+ 1%	+ 14%	↑
Increase in speed of mean reversion of inflows	- 1%	- 6%	↓

inflow seasonality leads to tiny decreases in both the expected spot price level and volatility in the spot price. Expected hedge strike prices fall, and demand for hedges falls. Hedge prices drop.

When inflow predictability decreases, there is a minor rise in the expected spot price, and a larger increase in its volatility. The increased risk leads to excess demand for hedges, which together with the higher expected spot price produces a higher hedge price. Lastly, an increase in the mean reversion speed of inflow leads to small decreases in both the level of the expected spot price and its volatility. Hedge demand rises.

Essentially, the figure illustrates how climate change affects hedging parameters through changes in the spot price. These hedging parameters matter: an increase in hedge prices, given the quantity of hedges, affects welfare through its effects on generator and retailer investment, transaction costs[63] and the cost of capital. Ultimately, this flows through to the price charged to final consumers.

63 Transaction costs are 'side costs' associated with entering into a market exchange, e.g. the time spent looking for the mobile phone that will provoke the most jealousy among your peers!

7 Water allocation more generally

You would be robbing yourself of insight if you saw the electricity market solely as an electricity market. From learning how hydro generators use the water shadow price to shape their generation decisions, we see that the electricity market, as well as allocating inputs such as gas, is also a market for water. The shadow price of water affects how vast quantities of water are utilised by society, and hence how they affect social welfare in New Zealand. It prices water in each of the catchments where there are hydro generators; and it values water, taking into account substitution across catchments through the electricity water market, substitution with gas as well as the demand for electricity (in general and in catchments).

The electricity market, then, plays a key role in the management of water. That is not to say it is the only avenue for water management – far from it. Though we all have a stake in the electricity market, we value water beyond its use in keeping the lights on. Water has immense cultural and environmental value, including for Māori as tāngata whenua. In addition to energy generation it also has value to agriculture, horticulture, recreation, tourism, ecology and tourism.

7.1 Whither the water?

Hydro generators derive their demand for water from others' demand for electricity – they value it as an input into production, as well as an end good. We can understand this demand by thinking about the mismatch problem discussed in the context of seasonal generation: the hydro generator receives lower inflows when electricity demand peaks, but can resolve this issue by storing summer inflows for winter where facilities are available. That is, in summertime hydro generators demand in advance the amount of stored water they expect to use in winter.[64]

Hydro generators are not the only ones concerned about the level and seasonal availability of water. New Zealand is host to many other industries which create seasonally-based derived demand for water – dairy farming, golf, and winemaking all readily spring to mind. We may also add intrinsic household demand for water: plants do not water themselves, and the car might be in need of a good wash.[65]

In the face of conflicting demands for water, two questions arise: what use takes priority, and who decides? Generally, it is desirable to leave resource management decisions to competing users, who have both the incentive, information and the means to allocate the resource most efficiently. Users bear the direct costs of inefficient management, of which central authorities may be less aware of – especially when being pressured by lobbyists and the threat of political capture. Users are also in the best position to assess how much they value the resource in their individual uses.

All of this points to the establishment of a broader water market that enables substitution among all socially valuable uses of water. For a

64 This is an illustration of how supply and demand interact with each other: until hydro generators have formed expectations of what electricity demand will be in the future, they will not know how much water they should store and hence what future supply will be.

65 While writing this monograph, the Wellingtonian authors were temporarily subject to an outdoor water ban owing to the North Island drought. The plants indeed did not water themselves and the irony has not been lost on us.

reasonably liquid water market to exist (no pun intended),[66] there should be well-defined water rights, the private exchange of such rights and minimal transaction costs.[67] Presently there is scope for water trading under the Resource Management Act 1991, the statute which governs natural resource use in New Zealand. However, such trading has not been widely taken up due to a host of legislative and non-legislative barriers.[68]

The key role of an effective water market is to allow water to travel to its most socially valued use, and the one that yields the highest net benefit to society. This use will not always be in the electricity market. For example, one formal cost-benefit analysis (CBA) undertaken in 2009 showed that Waikato River water was more socially valuable when used for dairy farm irrigation than hydro generation, even where irrigation was assumed to be a consumptive use.[69] The CBA was undertaken on a nationwide basis, and so captures public net benefit: private costs and benefits plus externalities (costs and benefits not directly borne by resource users).

We note the year that the CBA was undertaken, as the most efficient use of a resource of the day may not be the same in the future. To take a common example: a gardener may use a quantity of tank water to water pumpkins daily, but may prefer to use the pumpkin water in a few days to put out a small fire. This uses the same logic as in the within-day and between-season fuel substitution stories.

However we allocate water, there will be disgruntled parties. There was a possibility in the Waikato River case that allocating water to farm irrigation could result in a rise in the electricity price (albeit of negligible size).[70] It is a rare consumer who is delighted by the thought of rises in the power bill. However, New Zealanders benefit collectively when water goes to its socially most highly valued use. In this example, irrigation increases dairy farm productivity, boosting export receipts and growth. This is not to be sneezed at, considering that dairying is New Zealand's top merchandise export earner, contributing around 2.8% to New Zealand GDP and hence to household welfare.[71]

7.2 No such thing as free water

The ability to take a birds-eye view is crucial. Suppose that the government legislated to provide blocks of free electricity to household consumers, an idea that has recently been suggested in the media.[72] It is a very appealing thought, for few people are charmed by winter power bills. However, we quickly run back into our original problem: how to allocate scarce resources among countless uses.

There seem to be three elements to the proposal: a) that water is free, b) that New Zealand's electricity price has risen quickly relative to the rest of the world since the electricity market reforms starting in the 1980s, and c) that many electricity plants were constructed and paid for in the past, and hence the costs are no longer relevant. Each calls for deeper interpretation to determine their relevance. None justify the proposal.

In answer to the first claim, water is not free. It has alternative uses over time, via storage in electricity, and alternative non-electricity uses. Its opportunity cost influences and is affected by the use of other natural resources, such as gas.

The second claim must relate to the price of electricity and not to the household cost of electricity, because prior to the changes of the 1980s, households as taxpayers footed the bill for much of the electricity infrastructure and plants. Therefore, the electricity price to households and businesses at that time did not incorporate the full cost of electricity production and investment. Now, electricity prices cover production and investment costs, and the industry is not cross-subsidised by taxation. Prices before the 1980's changes did not indicate the true cost of electricity to households.

Lastly, the third claim is a common misconception: it ignores that water has a value of its own separate from the costs of infrastructure: it is not free, as we have shown.[73] In our model, infrastructure was taken as free, water was valued and hydro generation was most assuredly not free.

To maximise social benefit, the opportunity cost of using a resource needs to be paid by each

66 The liquidity of a market refers to the ease with which participants can trade a good or service.

67 See: Evidence given by Lewis Evans (15 October 2010) in *Re Resource Management Act 1991* EnvC Auckland ENV-2009-AKL-313-000005.

68 For further reading, see: Hawke, Richard (May 2006) "Improving the Water Allocation Framework in New Zealand: Enhanced Transfer", Ministry of Economic Development Occasional Paper 06/09. Accessed at http://www.med.govt.nz/about-us/publications/publications-by-topic/occasional-papers/2006/06-09-pdf.

69 The analysis ignored the historical capital cost of hydro. The cost-benefit analysis forms part of the evidence at note 47. Hydro generation was assumed to be a non-consumptive use, so it would be even more socially worthwhile to have irrigation downstream from hydro plants. That way, both parties are able to use the water.

70 Ibid.

71 Ministry for Primary Industries (12 December 2012) "Dairy" Ministry for Primary Industries. Accessed 12 March 2013 http://www.mpi.govt.nz/agriculture/pastoral/dairy.aspx.

72 Susan Edmunds (10 February 2013) "Call for free power", New Zealand Herald. Accessed 10 March 2013 at http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=10864382). The article attributes the proposition to Geoffrey Bertram.

73 In her article, Edmunds reports that generators with historical plants (particularly hydro plants) revalue their assets according to the electricity price. This process is common in the economy. The value of dairy farms is determined by the price of milk. The more productive farms have higher valuations than other farms, and revaluations reflect price changes. For both farms and electricity firms, it is the price of electricity and milk that set the valuations. This is desirable because it sets the price for all firms at that price which is relevant for socially beneficial investment in expansion, or alternatively retrenchment. In neither agriculture nor electricity is the reverse relationship true – the direction of causality does not run from firm value to market prices

user. If the user cannot pay it, then the next best use of the resource is socially more valuable than the use currently being made of it; the resource is not being efficiently allocated. Households, too, should be able to earn the opportunity cost of electricity and by extension, water. The view that households intrinsically "deserve" an electricity subsidy is problematic – not all households are poor and not all businesses are flush with cash.

The price of electricity also creates household management incentives for socially desirable uses of resources. If the price is high, households may invest in insulation or alternative energy sources, or manage heating requirements more smartly. Indeed, this is part of the rationale for the emissions trading scheme that raises the price of carbon emitting activity so that substitutes by consumers and firms are encouraged. While a person struggling to pay the monthly power bills would be understandably galled by this, to ignore household energy-saving incentives as the proposal does is no solution. Any additional consumption induced by the provision of free power, and any electricity economies that fail to be induced under free power will have additional resource costs, since they imply more generation, higher prices or both.

Finally, free electricity is equivalent to the government paying a chunk of our electricity bills. This is because three of the five major generators are state-owned.[74] The idea is certainly palatable to some, but like the first domino being knocked over, it has widespread effects on the efficient allocation of resources. Why free electricity in the face of other initiatives, like education or child poverty? Why households and not vineyards or dairying?

Of course, there is also the question of how the government would make up the resulting shortfall in its books. Taxation is always an available tool, but raising taxes itself affects the use of various resources. To flog a dead horse, there is no such thing as truly free electricity. The electricity (water) market is capable of allocating water to its most efficient use, in times of plenty and times of scarcity. We should be able to justify why water in the electricity market should be allocated to that use – electricity is not intrinsically more special than any other use. It is preferable that we have pricing arrangements that encourage competing uses to manage water efficiently within their markets, in ways that reflect the value of water in electricity and other applications.

Whichever system of allocation is settled upon, there will certainly be trade-offs. The private trading of well-defined water rights with minimal transaction costs, as we have suggested, is socially desirable.[75]

74 Ministry of Business, Innovation & Employment (9 December 2011) "Electricity industry – Electricity generation" Ministry of Business, Innovation & Employment. Accessed 12 March 2013 at http://www.med.govt.nz/sectors-industries/energy/electricity/industry/electricity-generation

75 See: Kevin Counsell, (2003) *Achieving Efficiency in Water Allocation: A Review of Domestic and International Practices*, NZ Institute for the Study of Competition and Regulation. Accessed at http://www.iscr.org.nz/f208,4297/Water_Allocation_101003.pdf, See also Counsell's paper Managing Water Quality and Allocating Water (October 2012), Third Report of the Land and Water Forum (accessed 6 March 2013 at http://www.landandwater.org.nz/.

8 Final Comment

It is hard to look out across Lake Wanaka or the Clutha River and not feel as if our country is exceptionally rich in water resources. Unfortunately, New Zealand is not some paradise with a never-ending supply of water. We ask the same questions as the rest of the world. Who do we allocate to? When and how much do we allocate?

The touchstone of this paper is a model of the NZEM market, which explains how the market is capable of allocating water and other resources in a way that maximises social welfare, within the bounds of the market. Various disruptions may alter the size of the welfare pie, but the smooth running of the market ensures that it is the largest size possible given the situation. We see that hydro storage and gas generation play a significant interactive role in the management of climate cycles and sudden events.

Efficient allocation requires both spot and hedge markets. They combine to produce a mix of short and long term markets that is common for commodities. They provide for the evolution of prices and quantities of electricity that change as resource supplies – e.g. water and gas – change, perhaps in response to climate conditions.

We all have an interest in how water is allocated in the wider economy. It is not enough to take a telescopic view of a single market, whether electricity or otherwise, and rest on our laurels happy that it is efficiently allocated in that market. It is, quite understandably, difficult to take a broader view, but the efficient allocation of water has profound implications for the performance of the New Zealand economy and social welfare.

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