Swapping Generators' Assets: Market Salvation or Wishful Thinking?

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Abstract

The idea of rearranging generation assets amongst firms to improve competition has once again surfaced in a recent report on improvements to the New Zealand Electricity Market. We show with examples that rearranging assets, either with asset divestiture to a new firm, or asset swaps between existing firms, may actually reduce competition in electricity markets. Our examples emphasize features that are particular to electricity, such as seasonality and transmission constraints. These results warn that applying economic rules of thumb to electricity markets may lead to erroneous conclusions.

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1 Introduction

In April 2009 the New Zealand Commerce Commission released a report undertaken by Stanford University Professor Frank Wolak (Wolak, 2009) that assessed the performance of the New Zealand Electricity Market (henceforth NZEM). This study concluded that there was evidence firms were exercising market power, and provided estimates of how frequently this occurred and the resulting markup in cleared prices. Wolak also concluded that the bulk of this exercise of market power happened during dry periods such as the summer of 2006, when water inflows into New Zealand's hydro storage lakes were low. The Wolak report contained a number of suggestions for the improvement of the NZEM. In particular it suggested an 'asset swap' between the North and South Island generators in order to enhance competition between thermal generators, especially during periods of water shortage.

Subsequent to the release of this report, a ministerial review of the electricity market was undertaken and a discussion paper was produced by the Electricity Technical Advisory Group (2009). This discussion paper also contained asset swap suggestions along the lines suggested by Wolak, as well as asset divesting options – breaking up existing firms to create additional firms in the market. In December 2009, the New Zealand Government released details of how it will rearrange the market. In particular, the Government intends to implement a 'virtual asset swap' by requiring generators in different islands to enter into long-term hedge contracts with each other.[1] This, they claim, is equivalent to a physical asset swap as recommended by the Electricity Technical Advisory Group (2009, Recomendation 17.3).

Worldwide, the breaking up and swapping of assets is relatively common in power markets. A recent example is the asset swap between German E.ON and Belgian Electrabel[2]. There are two broad arguments in favour. First, the breaking up and swapping of assets may stimulate competition in wholesale electricity markets, thereby lowering prices. Intuitively, breaking up and exchanging assets can lead to an increased number of players in a market. Classical results from economics literature state that in a Cournot game, as the number of players increases, the market clearing price approaches the marginal cost of production[3]. A second argument says that generators may be able to hedge their generation risks better by swapping assets, which could lead to a more efficient market. However, modelling risk attitudes related to asset swaps is a complicated task and beyond the scope of this paper. Therefore we will not model risk here and hope to return to this important question in a subsequent body of work.

In this paper, we consider the impact of asset divesting and swapping policies on prices and consumer surplus. Asset rearrangements are typically designed to increase the number of players in the market or submarkets, because as per

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[1] Available at http://www.med.govt.nz/upload/71002/cabinet-paper.pdf.

[2] http://pepei.pennnet.com/display_article/348301/6/ARTCL/none/ BUSIN/1/EON-to-swap-assets-with-Electrabel,-EnBW/

[3] See for example Tirole (1988) page 223.

the intuition above, increasing the number of players should have a positive effect on competition. We identify two distinct additional negative effects arising from such rearrangements, either of which can overwhelm this positive effect. The first is a potentially detrimental change in relative costs between differing generation technologies. We find that although an asset swap such as that suggested by Wolak increases the number of thermal generators and can enhance the market performance during dry periods, it can have the opposite effect during wet periods. This is because the value of water relative to the cost of thermal generation changes between wet and dry periods. Therefore the steady state production and hence the market clearing price will change[4]. We find a similar result for asset divesting. This work is related to that of Hope (2005), who observed that mergers of hydro and thermal generation can create firms who are in a stronger position to exercise market power. The second negative effect arises when transmission constraints exist. We show that, although asset swaps of the kind suggested by Wolak can enhance the market outcomes in a perfect market, they can lead to congestion when an underlying transmission system is involved. This is an example of the general theory of second best that manifests in economics literature frequently dating back to 1950s (Lipseyi and Lancaster, 1956). Here the introduction of an 'improvement' actually leads to line constraints binding which itself leads to

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[4] This will have the effect of decreasing the price in dry years, but increasing it in wet years, which will likely decrease price differences between wet and dry years. Paradoxically, this might have a beneficial effect, since it would decrease price risk for firms and consumers, all else being equal. However we have abstracted away from risk based arguments in this paper, so we do not explore this further.

a worse market outcome in steady state.

In the remainder of the paper, we begin by presenting a series of counterexamples showing that even in the simplest of markets without transmission constraints, both asset swapping and asset divestiture may lead to less competitive outcomes with higher prices. We then give additional counterexamples in both cases to demonstrate how network constraints can confound what would otherwise be a straightforward improvement in competition. We conclude with a specific case study of the New Zealand market, where we consider the probable impacts of the asset swap adopted by the Government.

2 Core Model

In this section we discuss how we model the strategic behaviour of firms using Cournot games over transmission networks. As with the traditional Cournot paradigm, we model strategic firms that commit to generation levels for each of their plants. Unlike traditional commodities modelled in a Cournot framework, electricity is not a storable commodity and its flow over a transmission network must comply with a set of physical constraints [5]. Once the firms commit to generation levels for each of their plants, prices are determined by an independent system operator (ISO), whose role is to choose line flows to maximize total welfare while ensuring the flows are compatible with the

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[5] We model the transmission network using a simple DC load-flow approximation without line losses. A detailed example of this type of power flow model can be found in Wu et al. (1996).

physical constraints. The payoff for each of the firms is calculated by their revenue (price × quantity) less their running costs, which are detailed in the following paragraph.

We allow for firms to own two types of generation technology, which for convenience we will call thermal and hydro. Each thermal plant has a quadratic cost function $c_T(q) = Tq + tq^2$, where q is electricity generation in MWh [6], and each hydro plant has a quadratic cost function $c_H(q) = Hq + hq^2$. We assume all the parameters H, T, h, t are non-negative. These cost functions will typically be different; for example we will always assume $H < T$, since the short-run costs of a hydro generator are almost always lower than those of a thermal generator[7]. Furthermore, we do not explicitly model any capacity constraints on generators, as we can set the h and t terms to act as a proxy for capacity constraints, since these can significantly steepen each respective generator's cost curve if set high. A particularly useful way to think about h is a measure of water scarcity. If h is low, hydro costs are low, indicating a surplus of water. A high h results in a relatively high cost for hydro generation, which can be thought of as a high opportunity cost resulting from a shortage of water.

We model demand for electricity at node i by a linear demand function of the form $D_i\left(p_i\right) = a_i - b_i p_i$, where p_i is the market spot price at that node, and

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[6] The cost is based on an instantaneous MW output i.e. Producing 100MW for one hour costs a different amount to 50MW for two hours.

[7] In a severe drought this might not be true, but we can manipulate h versus t to account for this and do so in our examples in this paper.

a_i and b_i are positive constants[8]. As outlined above, firms compete to satisfy this demand using a variation on the Cournot paradigm. Every firm chooses a quantity of electricity for each of its plants to sell. The market price at each node is determined from the conventional optimal power flow problem, solved by the ISO where the objective is to maximize total surplus over the network while complying with electricity flow constraints (Berry et al., 1999; Wu et al., 1996) [9]. This extension of the familiar Cournot model reduces to the conventional Cournot model when there is only one node in the network, or when there are no binding transmission constraints. Our choice of a linear demand function and convex cost functions for each generator ensures there is always a unique equilibrium outcome to our model in the default one-node case[10].

There are different ways of modelling Cournot competition in the presence of transmission constraints, depending on how much information is provided to the firms. Borenstein et al. (2000) analyze a full-rationality Cournot model, where the firms anticipate the effect their generation decisions have on congestion in the network and ultimately the nodal prices. In their paper, they present a collection of two-node examples and discuss the concept of a constrained Cournot equilibrium versus an unconstrained Cournot equilibrium. In the former, the transmission line linking the two nodes is constrained at

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[8] Note we assume elastic demand. Alternatively, we could assume inelastic demand with a competitive fringe to get the same results.

[9] The optimal power flow problem is repeated in the appendix of this paper for the reader's convenience.

[10] Uniqueness follows from, for example Vives (1999) pages 96-99 and Theorem 2.8.

equilibrium whereas in the latter, the line is unconstrained. The downside of a full rationality model of this type is that, in general, existence or uniqueness of pure-strategy equilibria cannot be guaranteed; we must now consider three possible types of equilibrium. One equilibrium can occur when the line is congested, another when the line is uncongested, and there may be a 'mixed strategy' equilibrium where there is a positive probability (but not certainty) that the line is congested[11]. An alternative approach is to use a bounded-rationality method (see e.g. Yao et al. (2008)) whereby firms are unaware of how their actions may affect congestion. The latter method is arguably less realistic, and does not capture the ability of firms to exploit transmission, however, a unique pure-strategy equilibrium is guaranteed. In this paper, as we are particularly interested in the impact of transmission, we employ Borenstein et al.'s full-rationality equilibrium concept, expanded appropriately to a network with any finite number of nodes. The optimization problem faced by the ISO is presented in the appendix.

3 Analysis of Asset Swapping

In this section we demonstrate how swapping of assets can lead to higher prices and reduced welfare results. These outcomes can occur despite the swaps we choose being aimed at increasing the number of firms owning thermal generators and the number of firms owning hydro generators; in other

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[11] When mixed strategy equilibria exist, there are potentially many such equilibria.

words, making the firms more symmetric. We discuss two features that are special to electricity markets. The first is the variable production costs of electricity when hydro resources generate a substantial fraction of the electricity in the market. An asset swap that might make sense in dry years may not yield the desired outcome in wet years. Our first example focuses on analyzing this effect in isolation. The second feature is the electricity transmission network. Electricity must be transmitted through a network and must comply with the physical constraints of such a network. These constraints can distort the effects of an asset swap in such a way as to reverse the intended outcome. We discuss an example that analyzes the effect of transmission network constraints on the asset swap outcome.

3.1 Without Transmission Constraints

Consider an electricity network with no transmission constraints[12], on which demand is given by $D(p) = 500 - p$. There are two firms selling electricity. Firm A owns two hydro generators and firm B owns two thermal generators. We fix thermal generation costs at $C_T(q) = 100q + 0.2q^2$, and hydro generation costs at $C_H(q) = 10q + hq^2$. Note that for the hydro costs we have fixed the coefficient on the linear term quite low relative to thermal generators, while we have left the coefficient on the quadratic term as a parameter, which we will alter to simulate wet versus dry conditions. We investigate a partic-

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[12] When there are no transmission constraints, we can model the network as a single node, as we have already assumed there are no line losses.

ular asset swap where firm A gives firm B a hydro generator in exchange for a thermal generator. This is illustrated in figure 1.

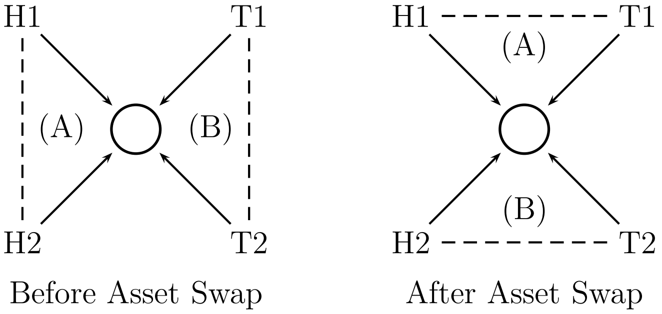

Figure 1: One-node asset swap.

First note that it is possible to choose specific parameters such that after the asset swap, consumer welfare[13] falls. Fix $h = 0.45$. Cournot competition before the asset swap results in a market price of 233.94. After the asset swap, the Cournot market price is 238.97 – a slight increase. Utilization of the hydro generators rises from 77.22 to 109.39, while utilization of the thermal generators falls from 55.81 to 21.13 (each).

However, an asset swap of this nature with no transmission constraints will typically improve welfare. In figure 2, we compare welfare before and after the swap across a range of possible hydro costs. We see that in a dry year or particularly wet year, the swap is welfare improving, and the market price falls. Interestingly though, when hydro costs are in the mid-range, the asset swap actually leads to higher market prices.

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[13] Throughout this paper, our measure of consumer welfare is consumer surplus.

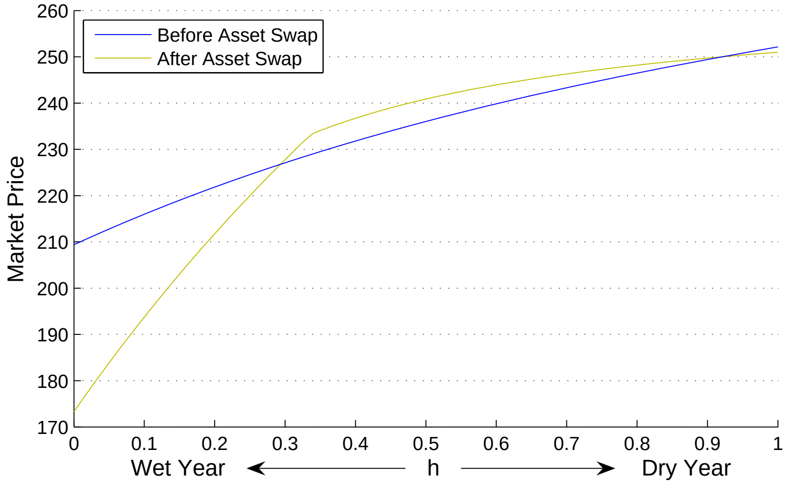

Figure 2: Market Price Before and After the Asset Swap

How do these results come about? In some respects, this result is intuitive. If hydro costs become very cheap, then firms will use mostly hydro generation. When one firm has a monopoly on hydro, then it can take advantage by restricting output, to push up the price. The other firm, owning thermal generators with their higher costs, is left at a considerable disadvantage. In this case, splitting the hydro generators amongst more firms improves competition. Here, the breakup of the hydro generator drives the result. On the other hand, when hydro generators are very expensive, the opposite intuition applies. Now thermal generators are pivotal, and the split allows for an extra competitor in the thermal market, again pushing down the price.

The asset swap changes the generation technologies available to each firm, causing a change in relative costs between the two firms. In either of the two cases above, one firm gains, lowering its costs relative to the other firm. The worst outcome for competition is in the middle range. Here, the swapping of assets leads to a slight reduction in total production of the plants. This is because there is insufficient increase in competition in hydro to offset the reduction in usage of the comparatively expensive thermals.

3.2 With Transmission Constraints

We now present a counterexample to demonstrate that the introduction of a transmission constraint can reverse what would otherwise be an improvement in competition. Consider a network with two nodes. At node 1, demand is given by $D_1(p) = 500 - 2p$, and at node 2 demand is given by $D_2(p) = 1000 - p$ [14]. There is a single transmission line connecting the two nodes, which we will assume has no line losses, but is subject to a capacity constraint, being able to carry only 500MW in either direction. Assume that hydro generation costs are $C_H(q) = 10q + 0.1q^2$, and thermal generation costs are $C_T(q) = 30q + 0.2q^2$. Here we have fixed $h = 0.1$, as we are no longer analyzing the effects of changing relative costs. Firm A owns two hydro assets at node 1, and firm B owns two thermal assets at node 2. Under Cournot competition, the initial prices before are $p_1 = p_2 = 219.88$, and consumer welfare is 305201.

Now perform a similar asset swap to the previous subsection – firm A gives

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[14] Having demand differ between the nodes facilitates our example by providing a reason for the ISO to utilize the transmission line.

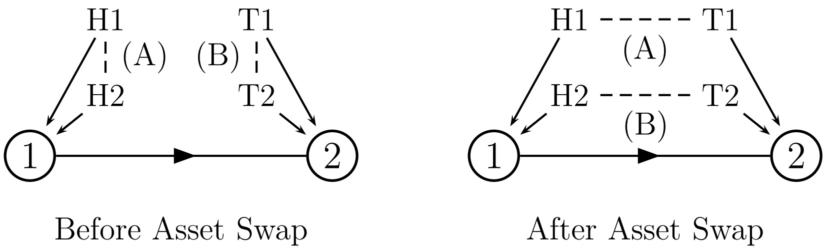

Figure 3: Two-node asset swap.

firm B a hydro generator in exchange for a thermal generator. If the line were unconstrained, after the swap, the prices at both nodes would be 215.69, and consumer welfare would rise to 308751. However, with the transmission constraint, the line becomes congested, and the firms withhold at node 2. The prices after the swap are instead $p_1 = 211.76$, $p_2 = 223.54$. Because demand is higher at node 2, there is an overall loss of consumer welfare, which falls to 302915 after the swap.

This counterexample illustrates the fundamental idea that transmission constraints can negate welfare improvements from rearranging assets. In the next section, we will demonstrate a similar result in the asset divestiture case with loop flows. The cause of the drop lies in strategic behaviour by firms. In our model, firms typically make higher profits when transmission lines are constrained, as this divides the network into submarkets with fewer players. Thus there are times when firms have an incentive to choose output such that the transmission line is congested in the resulting equilibrium. Paradoxically, since giving firms assets at multiple nodes is a stated goal of rearranging assets, this congested outcome is more easily achieved when firms have assets at both nodes, as now no firm loses market share due to a line congesting toward them.

4 Analysis of Asset Divestiture

In this section we demonstrate how divesting of assets to a new firm can also lead to higher prices and reduced welfare. We discuss the same two features that we did in section 3: the variation in the cost of water, and the impact of transmission constraints. We generate counterexamples to show that both features may cause asset divesting to lower welfare in electricity markets.

4.1 Without Transmission Constraints

Let demand be given by $D(p) = 500 - p$, and fix hydro generation costs at $C_H(q) = 10q + 0.1q^2$, thermal generation costs at $C_T(q) = 30q + q^2$. Now suppose there is a network with no transmission constraints, and two firms, each of which own one thermal and one hydro generator on the network.

Consider the following divestiture arrangement. A new firm is created, and is given a hydro asset from each of the existing firms. Before this divestiture, the Cournot market price is 193.14. After the divestiture, the Cournot market price becomes 205.41 – an increase over the initial price, indicating reduced competition. Thus we have created an example where the market has gone from two firms to three firms, yet competition is reduced.

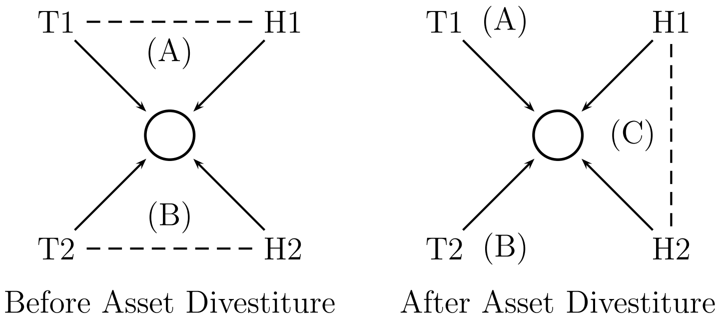

Figure 4: One-node divestiture.

This choice of example is obviously contrived, since it gives one firm all the low cost assets, whereas before they were split evenly. This leaves a single dominant firm, the new entrant, in the market, leading to a loss in competitiveness. Any other rearrangement of assets to form a new generator would have led to a welfare improvement, even giving the new firm two thermal generators.

Like the asset swapping case, this example works because of the difference in relative costs between the two different types of technologies. We have chosen $h = 0.1$, which means the hydro generators are relatively cheap to run. Figure 5 shows welfare before and after the divestiture as a function of h. If hydro costs were higher, then even this unusual asset divestiture would cause an improvement in welfare.

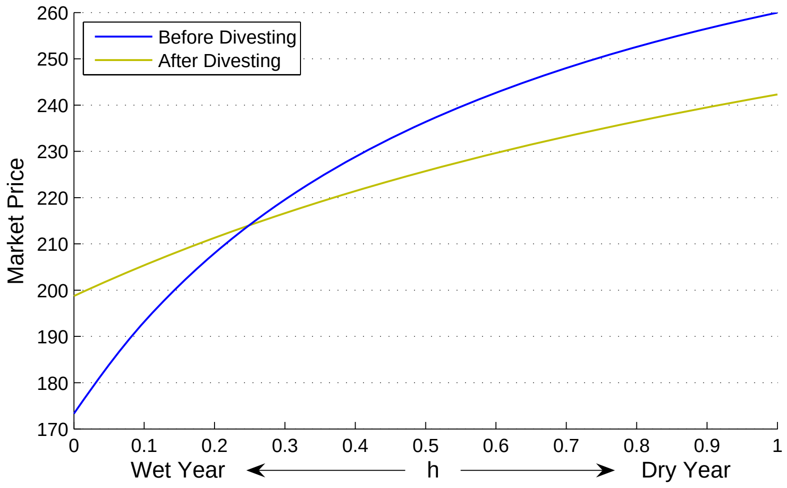

Figure 5: Market Price Before and After the Asset Divestiture

4.2 With Transmission Constraints

The previous section used asymmetric firms to demonstrate how an asset divestiture in a single node network could reduce welfare. Now we show that transmission constraints can cause the same effect, even when all generators are symmetric. We create a three-node network, depicted in figure 6. There is a single thermal generator at each node, with zero costs. There are two firms; firm A owns a generator at node 1, and firm B owns the generators at nodes 2 and 3. Demand at the three nodes is given by $D_1(p) = 100 - p$, $D_2(p) = 100 - p$, and $D_3(p) = 200 - p$ respectively. All transmission lines are assumed to have the same reactance.

First suppose there are no transmission constraints in the network. In this case, asset divestiture in this example would lead to an improvement in wel-

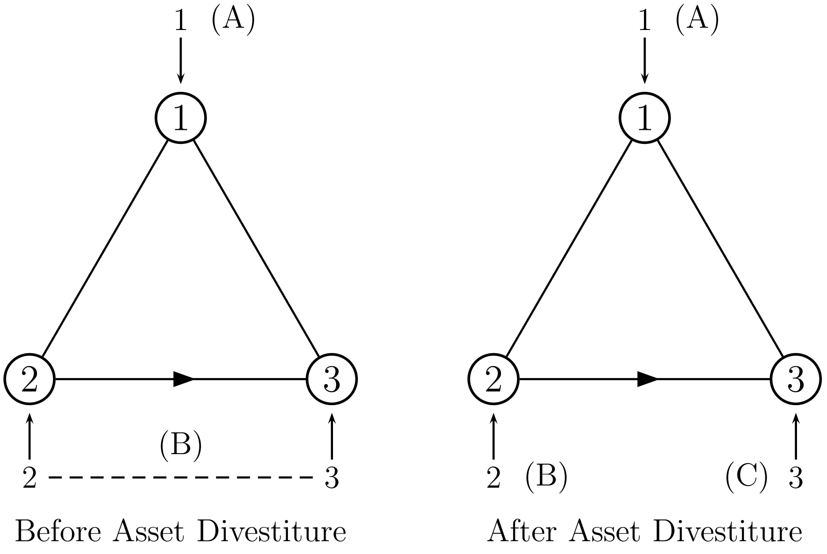

Figure 6: Three-node divestiture.

fare. Before divestiture, Cournot competition gives $q_1 = 133.33$, $q_2 + q_3 = 133.33$ and prices at all nodes equal to 44.44, resulting in consumer welfare equal to 15185. Suppose we now divest one of firm B's assets and give it to a new firm, denoted firm C. Each firm now owns one generator at a single node. After the divestiture, we have $q_1 = q_2 = q_3 = 100$, price equal to 33.33 at all nodes, and consumer welfare increases to 18333. In this case, each firm is paid the same price for electricity, and additional supply by any generator has the same impact on the price.

Now suppose the line between nodes 2 and 3 has a capacity constraint, say with maximum capacity K. If this line is congested in equilibrium, then the nodal prices, as a function of nodal injections, are[15]

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[15] Note that the prices at each node take on a form equivalent to a linear differentiated products inverse demand function. These price functions show that injections at nodes 2

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\begin{aligned}
p_1^* &= \tfrac{1}{3}\left(400 - q_1 - q_2 - q_3\right), \\
p_2^* &= \tfrac{1}{6}\left(500 - 2q_1 - 5q_2 + q_3\right) + \tfrac{3}{2}K, \\
p_3^* &= \tfrac{1}{6}\left(1100 - 2q_1 + q_2 - 5q_3\right) - \tfrac{3}{2}K.
\end{aligned}
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The new network constraint means that the value of the electricity produced by a generator is dependent upon the node at which that generator is located. If the injection at a node causes greater congestion on the constrained line, the marginal price at that node is lower than injecting at a node which relieves the congestion. Also note that injecting power at node 2 increases the price at node 3; this is due to the loop constraint requiring that additional power be exported from node 3.

Using the price functions derived above, and setting $K = 20$, the equilibrium before divestiture is now $q_1 = 133.33$, $q_2 = 56.67$, and $q_3 = 76.67$ (recall generators 2 and 3 are owned by the same firm), prices are $p_1 = 44.44$, $p_2 = 34.44$, and $p_3 = 54.44$. After divestiture, the equilibrium becomes $q_1 = 142.86$, $q_2 = 46.23$, $q_3 = 68.05$, with prices $p_1 = 47.62$, $p_2 = 38.53$, $p_3 = 56.71$. Consumer welfare falls from 14285 to 13527.

Once the generation at node 3 is divested to a new entrant, firm B (at node 2) is no longer concerned with the impact of its generation on the price at

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and 3 are complements, whereas an injection at node 1 substitutes for those at nodes 2 and 3.

node 3. Due to the fact that the electricity generated at nodes 2 and 3 are strategic complements (producing more at one node increases the incentive to produce more at the other node), having both generators owned by the same firm, actually increases the output of the generators and lowers the prices at all nodes in the network. Again, as in the asset swapping example, the existence of transmission constraints renders invalid the intuition that asset divestiture automatically improves competition.

Finally note that the key constraint here is the loop effect. Unlike our previous congestion counterexamples, here the constrained line is congested both before and after asset divesting, however welfare is still worse after the divestiture.

5 Case Study: The New Zealand Market

We now turn to analyzing the specific asset swap recommended for the New Zealand Electricity Market. The Cabinet Paper issued by the Government team made it clear that the physical swap of the Manapouri hydro plant for the E3P and P40 thermal plants was their preferred option. However, conducting this actual physical swap was considered infeasible, due to existing contracts with major users, notably Rio Tinto.[16] Therefore the team proposed:

> "The effects of a substantial physical asset swap (of a similar size

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[16] See http://www.med.govt.nz/upload/71002/cabinet-paper.pdf, Note #30.

> to swapping Manapouri and e3p and p40) could be simulated by a one-off exchange of long term hedge contracts among the three generator-retailer SOEs."

Analyzing hedge contracts is beyond the scope of our model. However, it is clear from the Cabinet Paper that the intent of the reform is to mimic the physical asset swap described above. This is the asset swap we now examine.

5.1 The Model

New Zealand has two main islands, the North and South Islands, whose power grids are connected by a high voltage direct current (HVDC) line. The North Island is more populated and industrial, making it the source of much of the load. However the South Island has most of New Zealand's hydro generation, so the HVDC line is a critical link in the network.

We model this by assuming the market operates over two nodes, which represent the South Island and the North Island. The two islands are linked by an transmission line with fixed transmission capacity (set at $K = 260$MW) and no line losses, which represents the HVDC line. We allow for four firms in the market. Initially Firm A owns two hydro generators in the South Island, firm B owns two thermal generators in the North Island, firm C owns one hydro generator in the North Island, and firm D owns one hydro generator in the South Island, and one thermal generator in the North Island. The cost functions for each hydro generator is $c_H(q) = 10q + hq^2$, whereas the cost function for each thermal generator is $c_T(q) = 30q + 0.2q^2$. As discussed in section 2, we choose these cost functions to ensure hydro plants generate electricity more cheaply than thermal plants, and the h parameter allows us to change the value of water, altering the relative costs of the two technologies. We assume demand is $D_S(p_S) = 500a - 1.5p_S$ and $D_N(p_N) = 1000a - p_N$ in the South and North islands respectively. The parameter a is a variable representing the demand level in New Zealand.

We model the asset swap as an exchange between firm A and firm B. Firm A gives one of its South Island hydro generators to firm B, and firm B gives one of its North Island thermal generators to firm A. We illustrate this swap in figure 7.

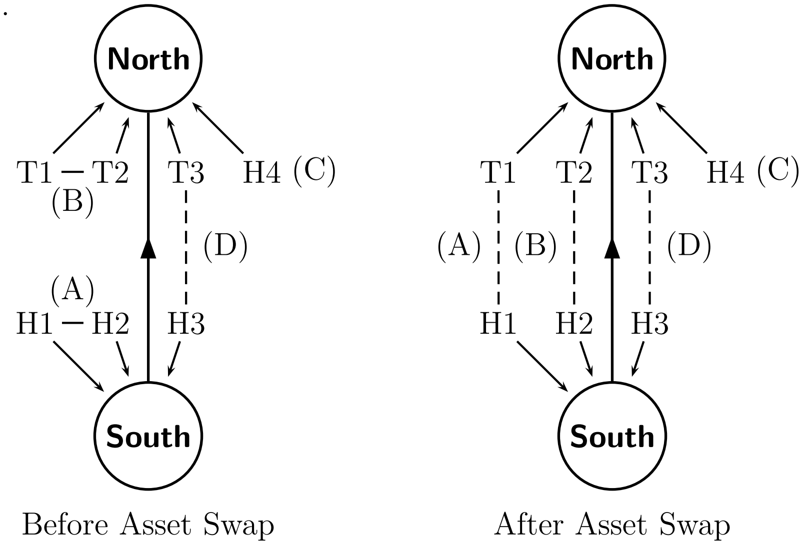

Figure 7: Asset Swap in New Zealand

We emphasize that although this model is inspired by the New Zealand market, it has no generator capacity constraints, no forward markets, and no other technical constraints aside from the HVDC line, and thus one should use caution in interpreting the results directly to New Zealand.

5.2 Without Transmission Constraints

We begin by discussing the impact of the asset swap ignoring transmission constraints i.e. assuming K is infinitely large. While obviously unrealistic, this assumption establishes an important base case against which we will later measure the effects of raising transmission capacity. The results are essentially identical to our unconstrained example in section 3. In figure 8, we graph the market price before and after the asset swap across the range of hydro costs, holding demand fixed at $a = 1$.

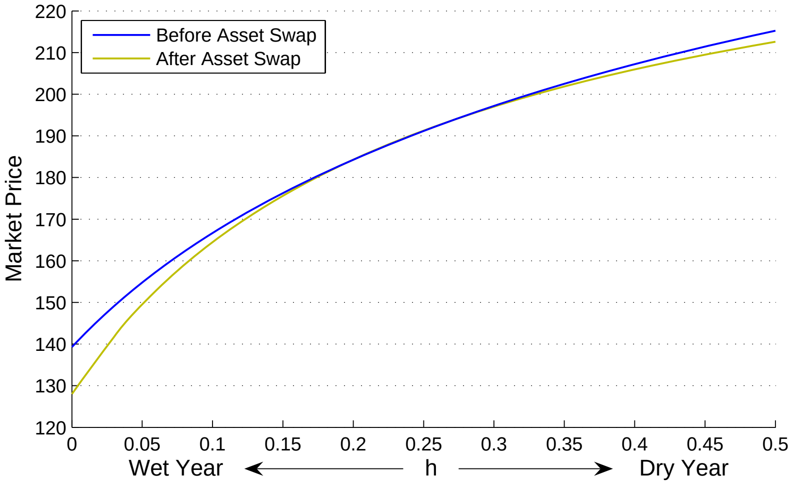

Figure 8: Market Prices Before and After the Asset Swap

We see the results are very similar to figure 2 in section 3. The price may decrease by as much as 8% as a result of the asset swap. On the other hand, the price after the swap does increase for a small range of h, in this case between 0.2 and 0.27. This is not visible in figure 8. The increase is minuscule compared to figure 2, reaching a maximum difference of 0.1034, or 0.05%. Thus in the New Zealand model, the asset swap generally improves welfare, albeit by a small amount, assuming the capacity of the HVDC capacity is sufficiently large.

Of more interest in the New Zealand model is how the asset swap affects utilization of the HVDC line. The swap has a significant effect on quantity of electricity produced by the two generation technologies. In a wet year, when hydro opportunity costs are low, the asset swap allows firm B to produce cheaper electricity using its new hydro plant. Firm A no longer monopolizes the South Island hydros, and given the parameters of our model, the net effect is that the two South Island hydro plants produce more electricity. Since the bulk of the demand is in the North Island, this significantly increases utilization of the HVDC line. In a dry year, thermal generation in the North Island increases after the swap, causing lower utilization of the HVDC line[17]. This effect is highlighted in figure 9.

This latter result is significant. Improving the geographic spread of the firms leads to greater use of the HVDC line as firms move to minimize their costs of generation. For this reason, if the line does have some maximum rated

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[17] In the south to north direction, or equivalently a higher flow in the north to south direction.

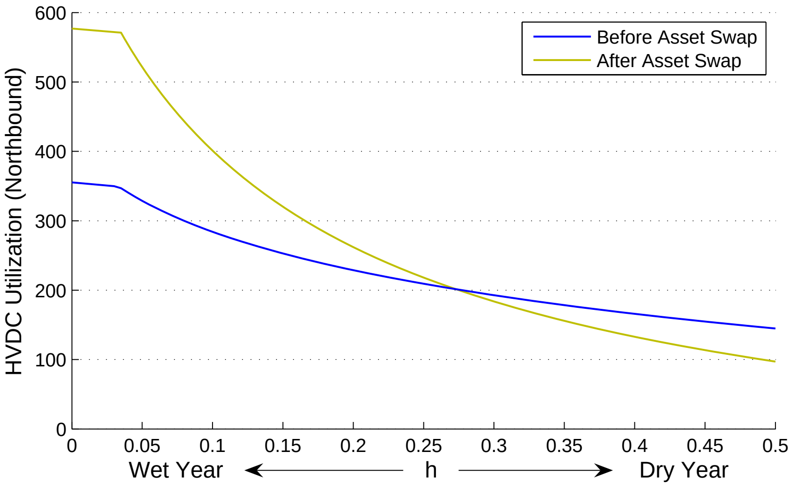

Figure 9: Utilization of the HVDC Line Before and After the Asset Swap

capacity, then it is more likely to be constrained after an asset swap than before. We will show in the next section that constraining the HVDC line can cause a large drop in welfare, a larger drop indeed than any potential improvement if the line does not congest.

5.3 With Transmission Constraints

The Ministerial Review raised concerns over the fact that, if the HVDC line were to become constrained, the New Zealand market would split into separate North and South Island markets. They noted that in this event, each island would have fewer firms competing (three and two respectively) than if the HVDC line were unconstrained. Both the Ministerial Review Team and Wolak highlighted the fact that an asset swap would increase the number of competitors in both islands, and that they argued, would drive down prices. These arguments are well recognized and true in isolation. However, there is a counter-effect not considered by the Ministerial Review. In section 3 we showed that an asset swap could cause a transmission line to ‘flip’ from uncongested to congested, with negative consequences for welfare. We will now show in the New Zealand model that when the HVDC line ‘flips’ to a congested state, the resulting decrease in welfare far outweighs the gain from having more firms in each island.

We fix $h = 0.2$ for the remainder of this section. This choice is deliberate. When $h = 0.2$ and the HVDC line is unconstrained, there are no welfare effects from the change in relative costs. The welfare changes we observe in this section can thus be attributed solely to transmission constraints and competition effects due to the asset swap. Allowing demand to vary around $a = 1$, we present one possible outcome of the asset swap on consumer welfare in figure 10.

When demand is low, the HVDC line is unconstrained before and after the swap, and there is no change in welfare (as we expected from our choice of h). When demand is high however, the HVDC line is constrained in equilibrium both before and after the swap. In this case we see a significant jump in welfare, as postulated by Wolak and the Ministerial Review. There are now a greater number of competitors in each island, who offer more electricity into the market in equilibrium. Thus prices fall in both islands, and consumer welfare rises.

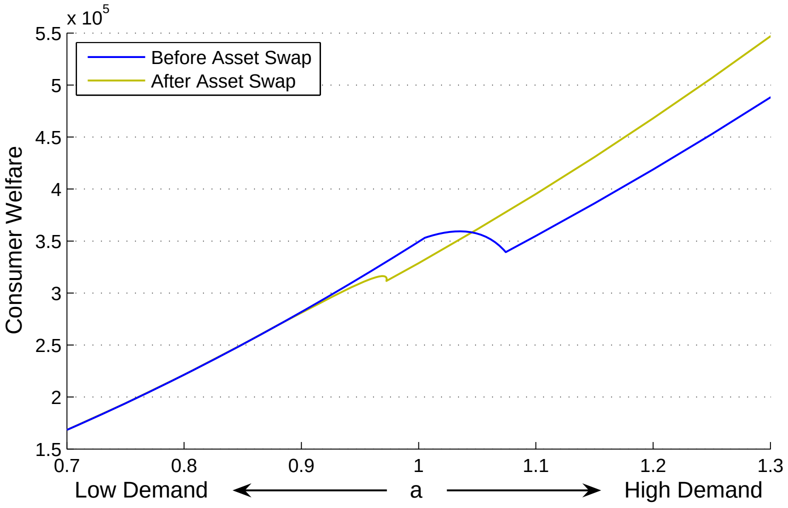

Figure 10: Consumer Welfare Before and After the Asset Swap

The most interesting case, however, is in the mid-range of demand. Here the 'before' scenario involved a single market with four firms. After the asset swap, the markets split into two, with three and four firms respectively. Although the South Island loses only one firm, and the North none, in the North Island in particular there is far less generation available. The generators take advantage of this to reduce their dispatch offers, so the asset swap causes quite a big decrease in welfare. We graph North Island prices before and after the swap in figure 11. On the other hand, prices in the South Island uniformly decrease after the swap. even though there are fewer firms. We graph South Island prices in figure 12.

The three graphs in figures 10 – 12 indicate that, for our choice of parameters, an asset swap is effective in increasing welfare when the HVDC line

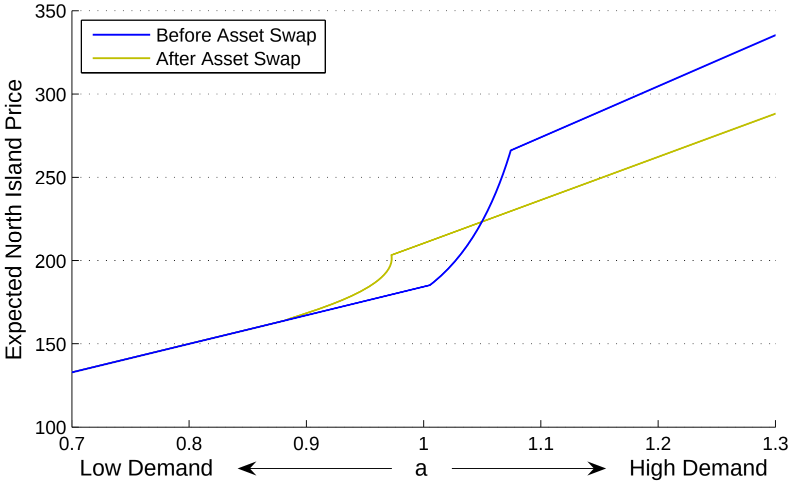

Figure 11: North Island Prices Before and After the Asset Swap

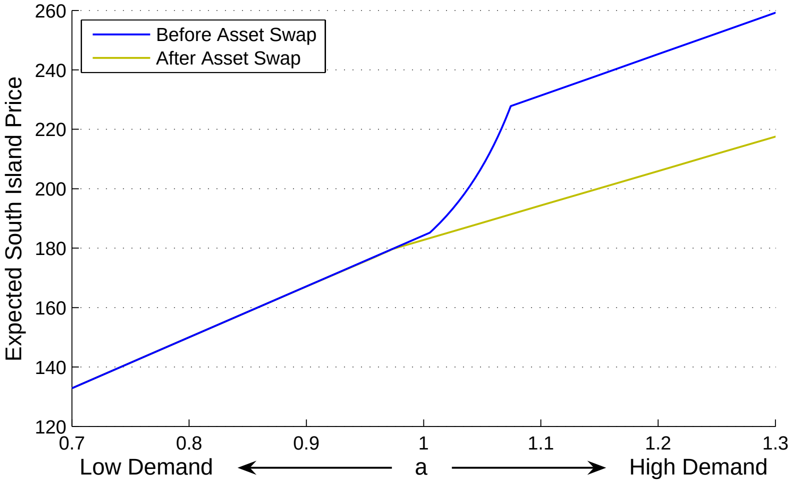

Figure 12: South Island Prices Before and After the Asset Swap

is frequently congested. This result agrees with the intuition expressed in the Wolak and Ministerial reports. However, when the HVDC line is initially uncongested, such as when demand is low, our model predicts one of two outcomes. Either there is no impact on welfare, or there could be a substantial decrease in welfare if the swap caused the HVDC line to become congested. Once again, we have held $h = 0.2$ for this section, and we know from the above results that for low or high h there may be a moderate increase in welfare when the HVDC line is uncongested. This increase should be accounted for when weighing the potential benefits and costs of any asset swap.

One of the most important points to arise from these results is the importance of the HVDC line. If the HVDC line had little capacity, then the constrained equilibria are most likely to arise, and our model would predict that welfare would normally rise as a result of the swap. On the other hand, if the HVDC line had limitless capacity, the asset swap policy would be largely ineffectual, with perhaps a small increase if h were particularly low or high. In the next section, we focus specifically on the interplay between HVDC capacity and welfare.

5.4 Increasing HVDC Capacity

The HVDC line is an important determinant of consumer welfare in New Zealand. Any congestion on the HVDC line splits the market into two.

This reduces competition, and often causes significant price differences between the two islands. The Wolak Report largely dismissed transmission constraints, noting that they occurred infrequently. However we have shown that in our model, the asset swap increases utilization of the HVDC line, potentially increasing the chance of congesting the line. In this next figure, we graph the HVDC's transmission capacity against consumer welfare, both before and after the asset swap, assuming $a = 1$ and $h = 0.1$.

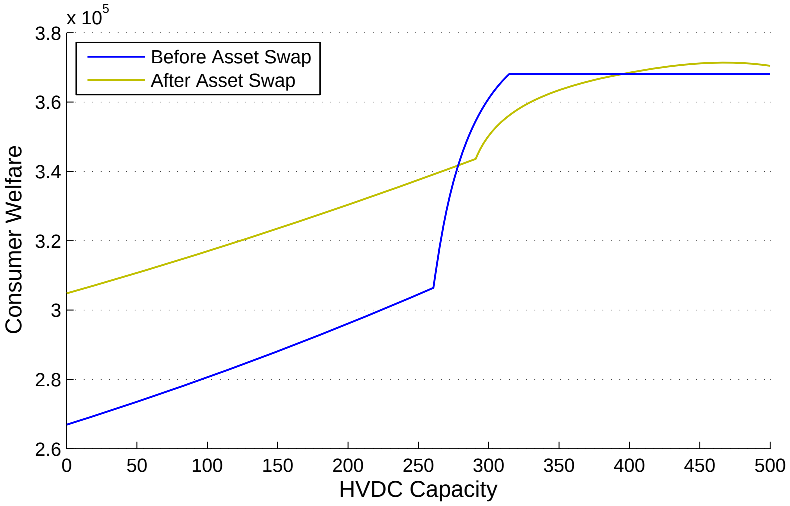

Figure 13: Welfare Before and After the Asset Swap as a function of HVDC Capacity

Our choice of parameters implies average demand and a relatively wet year, indicating a higher flow on the HVDC line. On the left hand side of the graph, the HVDC line is congested. As we would expect, increasing HVDC capacity increases welfare in this region, but there is also a large increase in welfare between $K = 250$ and $K = 300$ as the HVDC line transitions from congested to uncongested in the equilibrium outcome. Once the HVDC line is uncongested, there are no further welfare gains possible from adding additional HVDC capacity. Again, the benefit of an asset swap occurs primarily when the HVDC line is congested[18].

5.5 Summary

Our modelling suggests that New Zealand would derive most benefit from the asset swap if the HVDC line were heavily constrained. In this situation, the North and South Islands are separate markets, and there is considerable benefit in increasing the number of firms in each island. With the line frequently congested, the case where the asset swap causes the line to switch from uncongested to congested is likely to occur only at times of low demand. On the other hand, if the HVDC line is rarely congested, then our modelling suggests the asset swap has little benefit, and may even reduce consumer welfare.

We have identified additional benefits to the asset swap arising from changing relative costs, but these were small compared to welfare changes due to line constraints, and do not impact on the above conclusions. One major policy implication of our work is that increasing HVDC capacity could realize many of the benefits of an asset swap, without the negative consequences.

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[18] Note that any benefit of an asset swap would have to be weighed against the potential cost of the swap.

6 Conclusions

Asset swaps and divestitures beguile regulators looking for a quick and easy way[19] to improve competition in electricity markets. The idea that increasing the number of firms owning certain technologies, or located at certain nodes, increases competition is attractive, and easy to understand.

In this paper we have shown two factors that work against this intuition. The first is relative costs. When firms have a range of different technologies at their disposal, an asset swap or divestiture has the potential to cause a decrease in welfare. This is less likely to occur with asset divestitures, provided the proposed divestiture is sensible, but the possibility should be accounted for. An aggravating factor here is that relative costs may change seasonally if there are hydro generators in the mix, because the opportunity cost of water can change. Thus a rearrangement of assets that works, say, in wet years may do just the opposite in dry years. The second factor is network constraints. Network constraints can split markets into multiple submarkets. Commonsense intuition says that ensuring there are more firms within each submarket should increase competition; however, we have identified a mitigating factor. When firms own assets at multiple nodes, they have the ability (and incentive) to choose output to congest transmission lines, so a previously unconstrained equilibrium may now actually be constrained. In

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[19] Of course there are some costs to asset swapping or divesting, but these are minor compared to the cost of new generation. The Ministerial Inquiry estimated the cost of the asset swap in New Zealand to be between 13 and 44 million New Zealand dollars (Electricity Technical Advisory Group, 2009, p47).

the New Zealand example, we demonstrated that such an effect could occur for certain ranges of parameters.

Our results suggest that some caution be taken when considering asset rearrangements. The impact on welfare is highly dependent on the relative costs of various technologies, and factors such as hydro opportunity costs and varying demand. The costs and benefits of such a move should always be weighed up against alternative measures to improve the depth of the market, particularly improvements in transmission, which we showed to be potentially very beneficial in the New Zealand case.

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Appendix

ISO's Optimization Problem

Taking a vector q of injections, we solve the following convex dispatch problem to determine the optimal flows on the lines and nodal prices.

$$\begin{aligned}
\max \quad & \sum_{i \in N} \left(\tfrac{a_i}{b_i} D_i - \tfrac{1}{2b_i} {D_i}^2 \right) & \\
s.t. \quad & D - Af = Pq & [p] \\
& Lf = 0 & \\
& f \leq K & \\
& -f \leq K &
\end{aligned}$$

The objective is to maximize the total welfare; this consists of producer and consumer surplus and congestion rents. The first constraint is a node balance constraint, equating consumption less inflows to total production; here A is a node-arc incidence matrix, P is a matrix that maps plants to nodes and D and f are vectors of demand and line flows respectively. The next constraint ensures that the flows obey Kirchhoff's laws. The last two constraints ensure that the line flows do not violate the thermal limit on the lines.

The vector of dual variables associated with the node balance constraints give the nodal prices. These nodal prices are anticipated by the firms; each solving their profit maximization problem.