MODELLING THE HEDGING DECISIONS OF A GENERATOR WITH MARKET POWER

Darryl Biggar
Australian Energy Regulator
Melbourne, Australia
darryl.biggar@stanfordalumni.org

Mohammad Hesamzadeh
KTH, Stockholm, Sweden
mrhesamzadeh@ee.kth.se

Abstract – The incentive on an electricity generating firm to exercise market power depends strongly on the volume the firm has pre-sold in the forward or hedge markets. Therefore, in order to forecast the effect of mergers and other market developments on market power outcomes, it is essential to model the hedging decisions of dominant generating firms. This paper shows that a dominant firm's profit-maximizing choice of hedge level depends on the extent to which the hedge price varies with the firm's hedging decision. In the case in which the hedge price is independent of the firm's hedge level, the optimal choice of hedging is an "all or nothing" decision. In this case, there is no equilibrium level of hedging in pure strategies. This outcome may explain the observed lack of hedge market liquidity in wholesale electricity markets with substantial market power. We also model the equilibrium hedging outcome in a two-stage Cournot oligopoly and show that, even if the hedge price is independent of the hedging decisions of the firms, a rational expectations equilibrium can exist with high levels of hedging if there are enough firms in the market.

Keywords: Market power, strategic forward contracting, liquidity, Nash equilibrium, Cournot oligopoly.

1   INTRODUCTION

It is well-known that liberalized electricity markets tend to be prone to the exercise of market power. As a result, there is a great deal of interest among market regulators in developing effective tools for forecasting likely future market power following major market developments such as a merger of generating companies or an augmentation to the transmission network. Unfortunately, however, the incentive on a generator to exercise market power depends very strongly on the volume of output it has pre-sold in the forward markets. A generator which is hedged to a high level in the forward market has very little incentive to exercise market power in the spot market. Conversely, a generator which chooses to be largely unhedged may have a significant incentive to exercise market power in the spot market.

Existing approaches to forecasting market power typically take the level of hedge cover of a generator as an external, exogenous input to the model. But, in practice, the level of hedge cover chosen by a generator is not exogenous but is endogenous to the market structure and opportunities to exercise market power. Changes in the market structure will, in general, change the hedging incentives of the firms in the market. If we are to accurately forecast the likely impact of market developments on the exercise of market power we need tools which allow us to model the hedging decisions of a generator in the light of future opportunities to exercise market power.

Reference [1] surveys the existing techniques for detecting (ex post) and forecasting (ex ante) the likely exercise of market power in electricity markets.

The seminal paper on the competitive impact of forward markets on spot markets by Allaz and Vila [2] proposed that, in the presence of a forward market, firms would be led to sell a proportion of their output in advance, reducing the incentive to exercise market power in the spot market. This has subsequently been confirmed in empirical studies (summarized in [6]). [10] extends the modeling of Allaz and Vila to the case of more than two firms and differing variable costs.

Allaz and Vila, however, made a number of key assumptions, which have subsequently been challenged: Specifically: (a) that firms play a Cournot (or quantity) game in the forward markets and in the spot market; (b) that the forward contracting position of each firm is fully observable to the market; (c) that the price of the forward contract is always precisely equal to the expected future spot price; and (d) that each firm hedges with simple forward contracts (also known, in the context of electricity markets, as "swaps" or "contracts-for-differences"). [3] and [4] emphasize that if, instead, we assume Bertrand (or price) competition in the spot market it can be privately optimal for generators with market power to choose to be unhedged (or to go further, to purchase forward contracts – effectively resulting in a negative hedge position) so as to raise prices in the spot market. [4] and [5] generalize this further to the case of

competition in supply function equilibria. [7] explores the implications of allowing firms to hedge using option contracts (also known as "caps").

In common with the present paper, [8] and [9] explore the implications of dropping the assumption that the forward contract position of firms are observable. [8] shows that if firms cannot observe contract positions or prices then the only equilibrium is one in which firms do not hedge at all. But [8], following the normal approach in this literature, retains the assumption that forward prices are always equal to the expected future spot price. But the expected future spot price itself depends on the hedge levels chosen at the first stage. In order for traders in the forward market to drive the forward price to the expected future spot price, they must have information on the level of hedging chosen by all the dominant generators in the market. But in practice the level of hedging chosen by a generator is highly commercially sensitive information that is not normally available to the market. We consider the standard no-arbitrage assumption to be unrealistic. As in [9], our key point of departure from this previous literature is to drop this assumption. Specifically we will assume that arbitrageurs are not able to observe the hedge position of the domination generators. As a consequence, we consider the case in which a dominant generator is able to adjust its hedge level by a small amount without affecting the forward price. We look for a "rational expectations equilibrium" in which the expectations of hedge traders about expected future spot prices are fulfilled ex post. Importantly, we show that under this scenario, for small enough levels of risk-aversion, and assuming linear demand and constant marginal cost, there is no stable equilibrium in pure strategies. This arises because the profit function of the generators is U-shaped: the maxima lie at the extremes rather than in the interior. If hedge traders forecast low levels of hedging and therefore high future spot prices, and set forward prices accordingly, the generator with market power will choose a high level of hedging, forcing future spot prices down. Conversely, if the hedge traders forecast high levels of hedging and therefore low future spot prices, traders will set low prices for forward contracts. But in this case the generator(s) with market power will choose a low level of hedging, resulting in the exercise of market power in the spot market, forcing future spot prices up. As we will demonstrate below, this result holds for both a single dominant firm and a Cournot oligopoly although, as we will see, the larger the number of firms the more likely it is that there will arise a conventional competitive equilibrium in pure strategies.

We consider that this "no equilibrium in pure strategies" result reflects some key aspects of observed outcomes in the Australian National Electricity Market (NEM). Specifically, we argue that the outcomes in the South Australian region of the NEM, in which a dominant generator has exercised significant market power in the last few years (but not in earlier years), coupled with a simultaneous drop in liquidity in the forward market, is consistent with the outcomes of this model.

This paper also has direct implications for the assessment of mergers in the electricity market. According to the model set out in this paper, there may be something of a "tipping point" in wholesale electricity markets. With sufficiently low levels of market concentration an equilibrium can exist with an active hedge market and in which generators choose to be hedged to a moderately high level. However, a merger which increases market concentration in such a wholesale market can result in the market switching to one in which there is no equilibrium level of hedging – in which case hedge levels, hedge prices, and spot prices will be volatile, and the liquidity of the hedge market will significantly reduce.

Even if we make the assumption that the forward price somehow closely follows the hedging decisions of the dominant generators (which seems unlikely), a merger of two electricity generators can have a significantly larger impact on market power than a merger of two other firms in other sectors of the economy. The reason is that an increase in market concentration has a two-fold effect on market power: First, as in any other market, for any given level of hedging, an increase in concentration increases the price outcomes that are likely to result. Second, and in addition, the increase in concentration also tends to reduce the level of hedge cover chosen by the generators in equilibrium, further increasing the resulting price outcomes.

This paper has three main parts. The next part introduces the methodology and main results in the context of a single dominant generator in a market with uncertain linear demand and constant marginal cost. The third part generalizes this theory to the case of a many generators competing in a Cournot strategic game. The fourth part concludes.

2   THE HEDGING DECISIONS OF A SINGLE DOMINANT FIRM

Let's start by focusing on the hedging decisions of a single generating firm operating in a wholesale market with a degree of market power. Throughout this paper we will focus on the special case of linear demand and constant marginal cost.

In both parts of this paper we will focus on a two-stage decision problem. In the first stage the firm chooses the level of hedge cover, with knowledge of the range of demand conditions likely to arise in the future (and therefore any opportunities to exercise market power) and the prevailing hedge price. In the second stage the firm observes the actual demand and makes a decision on its level of output (which may include the scope to exercise any market power).

To keep the problem simple and to focus on the main results of interest, we will make the following simplifying assumptions: (a) the only hedging considered will be a simple swap or contract-for-differences; (b) the generator itself will be assumed to be perfectly reliable; (c)

the generator will be assumed to have a sufficiently low marginal cost such that, even if it produced at its full capacity, the wholesale price would be greater than its marginal cost.

Let's suppose that the residual demand function facing the firm at any given point in time is linear and downward sloping. If the output of the firm is q the resulting wholesale price will be $p(q) = \beta - \alpha q$ where both β and α are assumed to be positive random variables. Given a realization of the demand curve, the profit facing the firm is:

$$\pi(q|x, \alpha, \beta) = (p(q) - c)q + (f - p(q))x \qquad \dots (1)$$

Where c is the marginal cost of the firm, f is the price of hedge contracts (the forward price) and x is the level of hedge contracts chosen by the firm. Maximizing this expression gives the profit-maximizing dispatch of the generator and the resulting wholesale market price as a function of the hedge level and the demand parameters $q(x, \alpha, \beta)$ and $p(x, \alpha, \beta)$.

We will focus on the case of a firm with market power – that is, a firm which faces a downward sloping residual demand curve (i.e., $\alpha > 0$). For a given hedge level and realization of the demand parameters the profit-maximizing level of output of the generator and the wholesale market price can be written:

$$p(x) = \alpha s(x) + c \text{ and}$$

$$q(x) = \frac{1}{\alpha}(p(x) - c) + x = s(x) + x \qquad \dots (2)$$

Here $s(x) = (q_c - x)/2$ and $q_c = (\beta - c)/\alpha$ is the volume of output which would drive the price down to marginal cost. As expected, with linear demand and constant marginal cost, the profit-maximizing quantity lies halfway between the hedge level x and q_c, and the profit-maximizing price lies halfway between the marginal cost c and the price corresponding to the hedge level $p(x) = \beta - \alpha x$.

2.1 Hedge price independent of firm's hedge level

Now let's return to the first stage of the problem. The utility-maximizing choice of the hedge level will depend on how the hedge price f depends on the hedge level x chosen by this firm. The problem is that the hedge level of a firm is typically commercial-in-confidence and not typically available to traders in the hedge market. To proceed, therefore, let's make the assumption that, in the first instance, the price at which hedges can be traded is invariant to small changes in the hedge level. We will look for an "rational expectations" equilibrium in which trader's forecasts of the hedge level are confirmed ex post.

Given a realization of the demand parameters, we can write the profit function (1) in the form:

$$\begin{aligned} \pi(x) &= (p(x) - c)(q(x) - x) + (f - c)x \\ &= \alpha s(x)^2 + (f - c)x \end{aligned} \qquad \dots (3)$$

Since $s(x)$ is a linear function of x, and the coefficient α is positive, the second derivative of $\pi(x)$ with respect to x is positive. In other words, for any given hedge level the expected profit given in equation (3) is U-shaped – the choice of hedge level which maximizes the expected profit will be an all-or-nothing binary decision. The firm will either choose to be hedged to a very high level or will choose to be hedged to a very low (and possibly negative) level.

To make this more concrete, let's suppose that the uncertainty in the residual demand function is such that the value q_c is constant. In other words, let's assume that the demand curve essentially "pivots" around the quantity-price combination (q_c, c). Furthermore, let's assume that the output of the firm must lie between some minimum and maximum production levels, q^{min} and q^{max}, respectively. Since $q(x) = \frac{1}{2}(x + q_c)$, this implies that the hedge level of the firm must fall in the range between x^{min} and x^{max} where:

$$x^{min} = 2q^{min} - q_c \text{ and } x^{max} = 2q^{max} - q_c \qquad \dots (4)$$

Under the assumption that q_c is constant, and assuming the firm is risk-neutral, the expected profit of the firm can be expressed as follows:

$$E(\pi) = \overline{\alpha}s(x)^2 + (f - c)x$$

It is clear, as emphasized above, that this profit function is U-shaped in the level of hedge cover – that is, the optimal level of hedge cover will lie at the extremes rather than an intermediate value. The firm will choose the maximum level of hedging if and only if:

$$E\pi(x^{max}) > E\pi(x^{min}) \iff f > \frac{p^{max} + p^{min}}{2}$$
$$\dots (5)$$

Here $p^{max} = c + \overline{\alpha}s(x^{max})$, $p^{min} = c + \overline{\alpha}s(x^{min})$ are the expected price outcomes when the firm chooses the maximum and minimum hedging levels, respectively. Note that since $q^{max} > q^{min}$, $x^{max} > x^{min}$ and therefore, $p^{max} < p^{min}$.

Now let's explore whether or not there exists a self-fulfilling or rational-expectations equilibrium in pure strategies. A forward price f and a hedge level x is a rational expectations equilibrium if and only if x is a profit-maximizing choice of hedging given the forward price and, given that hedge level, the forward price is equal to the expected future spot price.

Let's suppose that traders in the hedge market expect the firm to choose the minimum level of hedging x^{min}. The corresponding expected price outcome is $E(p) = p^{min}$. Assuming effective competition between traders in the hedge market, the hedge price will be forced to this level $f = p^{min}$. But, given this hedge price the profit-maximizing level of hedge cover is (by equation 5), x^{max}, contradicting the original assumption. This proves that there cannot be an equilibrium in which traders expect the firm to choose the minimum level of

hedging. Similar arguments show that there cannot be an equilibrium in which traders expect the firm to choose the maximum level of hedging. We have therefore proven the following result:

Proposition 1 *Under the assumption of linear residual demand and constant marginal cost, if a dominant firm faces a downward sloping residual demand curve with the property that the profit-maximizing level of output is independent of the realization of the demand parameters, there is no rational expectations or self-fulfilling equilibrium in pure strategies in the level of hedge cover of the firm.*

Although there is no equilibrium in pure strategies, there is an equilibrium if the generating firm is risk-neutral and we allow the generating firm to select its hedge level randomly (that is, to choose a "mixed strategy"). Let's suppose that traders expect that the generating firm will select the level of hedge cover by tossing a coin – choosing the minimum level of hedge cover with probability 0.5 and the maximum level of hedge cover with probability 0.5. In this case, the hedge traders (who are assumed to be risk neutral) will set the hedge price equal to the expected future price outcome: $f = \frac{1}{2}(p^{max} + p^{min})$. Given this hedge price, the generating firm will be indifferent between choosing the maximum or minimum level of hedge cover, which is consistent with the hypothesis that the firm chooses the level of hedge cover by tossing a coin.

2.2 The experience in South Australia

This model seems to capture some features of a situation that arose in the Australian National Electricity Market (NEM). Although the NEM market is reasonably competitive at most times, problems can arise when transmission constraints limit flows into an individual region. The South Australian (SA) region of the NEM lies in the extreme western end of the NEM. Although the South Australian region is small (in terms of energy consumption or generation capacity) relative to the rest of the NEM, at times when transmission constraints into South Australia are binding, certain generators in SA have the ability to exercise market power (see [13]).

The largest generator in the South Australian region is the Torrens Island Power Station. At times when transmission limits into South Australia are binding, if the demand in South Australia is high enough, the South Australian demand cannot be met by the sum of other generating units in South Australia and the interconnector flows. At these times Torrens Island Power Station is "pivotal". Torrens Island Power Station has, on several occasions, exercised market power, increasing the wholesale spot price in South Australia close to the wholesale price ceiling (which was, at the time, $10,000/MWh).

Torrens Island Power Station is currently owned by AGL – the largest retailer in South Australia. The acquisition of Torrens Island by AGL was approved by Aus-

tralia's competition authority (the Australian Competition and Consumer Commission) in 2007. At that time there had been no evidence that Torrens Island was exercising market power and, in any case, it was argued that AGL would not have an incentive to exercise market power as it was primarily a retailer and therefore would not seek to increase the wholesale price. This analysis turned out to be wrong. On very hot (high demand) days in each of the subsequent summers, Torrens Island withheld capacity from the market, pushing the price up to very high levels.

According to industry sources, in 1999/2000, shortly after liberalization of the wholesale market in SA, AGL was overwhelmingly dominant as a retailer in South Australia and needed to procure a large volume of hedge contracts. The then owner of the Torrens Island Power Station was able to hold out for a high price/high volume/medium term hedging contract with AGL – essentially insisting that AGL purchase a large proportion of its hedging needs from Torrens Island – for a period of 5 years. Under this contract Torrens Island was highly hedged and chose not to exercise market power. Average prices in South Australia during this period were moderate.

Around 2006, when this hedge contract expired, AGL's retail load was smaller. It found that it was able to cover its retail load with hedge contracts purchased from other generators and did not need to approach Torrens Island. With contract prices lower, Torrens Island did not choose to be contracted. At that time Torrens Island was sold to AGL. However, it seems plausible that the subsequent exercise of market power would have occurred even if Torrens Island remained with its previous owners. Subsequently, it appears that the owners of Torrens Island chose to maintain a largely unhedged position and to exploit opportunities to exercise market power when they arose.

This exercise of market power has had the effect of reducing liquidity in the hedge market. Reports from the Australian Energy Regulator show that the volume of exchange-based and over-the-counter in South Australian hedge contracts has declined significantly since 2006 (figure 3.10 in [11]). A survey of market participants in South Australia in mid-2010 found that the hedge market in SA was illiquid [12].

This experience appears to be consistent with the analysis set out above. Specifically, the large variation in the hedge level of the dominant generator, the resulting large variation in the wholesale spot prices, and the subsequent reduction in liquidity in the hedge market are consistent with the model set out above.

2.3 Hedge price dependent on firm's hedge level

To explore the significance of the assumptions about the actions of traders in the hedge market, let's consider the implications of the standard "no arbitrage" assumption. Specifically, let's suppose now that, given a level of hedge cover by the dominant firm, arbitrage in the hedge market pushes the hedge price down to the expected future spot price, so that: $f = E(p(x))$ (as noted

earlier this assumes that forward market traders can observe the hedge position of the dominant generator). As before, to keep the analysis simple, let's assume that the uncertainty in demand has the property that q_c is constant. Furthermore, let's assume $q^{min} \leq \frac{1}{2}q_c \leq q^{max}$ which implies that $x^{min} \leq 0 \leq x^{max}$. (This assumption is necessary to ensure that the profit-maximizing level of hedge cover is an interior maximum). Assuming risk neutrality, the expected profit of the firm is:

$$
\begin{aligned}
E(\pi) &= \overline{\alpha}s(x)(s(x)+x) + (f - E(p(x)) \\
&= \frac{\overline{\alpha}}{4}(q_c^2 - x^2)
\end{aligned}
\quad \text{...(6)}
$$

Under the assumptions above this expression has a unique interior maximum at $x = 0$. In other words, in a market in which traders can observe the hedge position of the dominant generator, that firm will choose to be completely unhedged.

This result is consistent with the conclusions in [7]. However, we consider this result is implausible in practice as it requires hedge traders to have detailed information about the hedge level of the dominant firm – information which they would not normally have available.

Do these results extend to the case of several firms with market power? This is the question we explore next.

3   HEDGING IN A TWO-STAGE OLIGOPOLY

The analysis above dealt with the case of a single dominant firm. Let's now consider extending the analysis to a simple Cournot oligopoly. Let's assume that we have a set of n unconstrained generators which, in the second stage, compete in a Cournot (or quantity) game. Let's also assume that there are a set of capacity-constrained generators producing the total output K. The total output in the wholesale spot market is therefore $Q = K + \sum_{i=1}^{n} q_i$.

As before we will assume linear demand and constant marginal cost. The marginal cost of the ith oligopoly generator will be denoted c_i. As before, the linear wholesale market demand curve will be represented by $p(q) = \beta - \alpha q$ where β and α are random variables.

Each unconstrained generator is assumed to choose a level of output which maximizes its profit given the level of output of the other unconstrained and constrained generators. The profit function of the ith generator is given by equation (1) above. From the first-order conditions with respect to q_i, the price and the level of output which maximizes profit (assuming an interior maximum $q_i^{min} \leq q_i \leq q_i^{max}$ for each unconstrained generator) is as follows (these equations generalize equations (2)).

$$ p(X) = \alpha s(X) + \overline{c} \text{ and} $$

$$ q_i(X, x_i) = s(X) + x_i + (\overline{c} - c_i)/\alpha \quad \text{...(7)} $$

Here $s(X) = (q_{\overline{c}} - X - K)/(n+1)$, $X = \sum_{i=1}^{n} x_i$, $q_{\overline{c}} = (\beta - \overline{c})/\alpha$, and $\overline{c} = \sum_i c_i/n$. As before, for simplicity let's make the assumption that $q_{\overline{c}}$ is constant. The profit of generator i in the first stage of the game is therefore (as in equation (3)):

$$
\begin{aligned}
\pi_i(X, x_i) &= (p(X) - c_i)(q_i(X, x_i) - x_i) + (f - c_i)x_i \\
&= \alpha(s(X) + (\overline{c} - c_i)/\alpha)^2 + (f - c_i)x_i
\end{aligned}
\quad \text{...(8)}
$$

As before, since $s(X)$ is linear in x_i, the expected profit is U-shaped in x_i. The profit-maximizing choice of x_i is not in the interior, but at the extremes.

3.1 Symmetric Cournot oligopoly

To proceed, let's assume that all the firms with market power are identical. We will look for a symmetric equilibrium. Specifically, let's assume that all the unconstrained firms have identical marginal cost c and upper and lower generating limits q^{min} and q^{max}. Let's focus on the hedging decision of firm i. Let's suppose that the other firms hedge to the total level X_{-i}. There are corresponding minimum and maximum level of hedging for firm i which we will denote $x_i^{min}(X_{-i})$ and $x_i^{max}(X_{-i})$. Firm i is assumed to choose the hedge level so as to maximize its expected profit. It will therefore choose the maximum level of hedging if and only if $E\pi_i(x_i^{max}, X_{-i}) > E\pi_i(x_i^{min}, X_{-i})$.

$$
\begin{aligned}
&E\pi_i(x_i^{max}, X_{-i}) - E\pi_i(x_i^{min}, X_{-i}) \\
&= \overline{\alpha}s(x_i^{max}, X_{-i})^2 - \overline{\alpha}s(x_i^{min}, X_{-i})^2 + (f-c)(x_i^{max} - x_i^{min}) \\
&= (x_i^{max} - x_i^{min})(f - \frac{p_i^{max} + p_i^{min} + (n-1)c}{n+1})
\end{aligned}
$$

Here $p_i^{max} = \overline{\alpha}s(x_i^{max} + X_{-i}) - c$ and $p_i^{min} = \overline{\alpha}s(x_i^{min} + X_{-i}) - c$ are the average prices that arise when the firm hedges to the maximum and minimum level, respectively.

Let's look for an equilibrium in which each firm hedges to the maximum level (this is the most competitive outcome). Each firm will choose the maximum level of hedging if and only if:

$$ f - c > \frac{(p_i^{max} - c) + (p_i^{min} - c)}{n+1} \quad \text{...(9)} $$

Let's define the maximum level of hedging for a generator, when all the other generators choose the maximum level of hedging, to be: $x^{max*} = L_n^{max} + q^{max}$, where $L_n^{max} = nq^{max} - q_{\overline{c}} + K$. L_n^{max} is positive if and only if when every generator is offering its full output to the market, the price falls below marginal cost. Let's suppose that every other generator in the market is hedged to level x^{max*}, and find the maximum and minimum levels of hedging for the remaining generator. The maximum and minimum hedge levels are given by $q(x^j|X_{-i}) = q^j$ where $j \in \{max, min\}$. Solving to find x^j we find that:

$$q(x^j|X_{-i}) = s(x^j + X_{-i}) + x^j = q^j$$
$$\Longleftrightarrow \quad x^j = L_n^{max} + q^j - (q^{max} - q^j)/n$$

Similarly, the price outcome when the firm chooses the maximum and minimum level of hedging (and every other firm chooses the maximum level of hedging) is given by:

$$
\begin{aligned}
p(x^j|X_{-i}) - c &= \alpha s(x^j + (n-1)x^{max}) \\
&= \alpha(q^j - x^j) \\
&= -\alpha L_n^{max} + \frac{\alpha}{n}(q^{max} - q^j)
\end{aligned}
$$

Let's look for a rational-expectations equilibrium in pure strategies. Let's suppose the hedge traders assume that all generators will hedge to the maximum level. The resulting hedge price will be $f = p^{max} = \overline{\alpha}s(nx^{max*}) - c$. Given this hedge price, using (9), we see that choosing the maximum level of hedge contracting is a Nash equilibrium if and only if:

$$
\begin{aligned}
f - c &> \frac{(p^{max} - c) + (p^{min} - c)}{n + 1} \\
\Longleftrightarrow \quad n(p^{max} - c) &> (p^{min} - c) \\
\Longleftrightarrow \quad -L_n^{max} &> \frac{(q^{max} - q^{min})}{n(n-1)} \\
\Longleftrightarrow \quad p^{max} - c &> \frac{\overline{\alpha}(q^{max} - q^{min})}{n(n-1)}
\end{aligned}
$$

From this result we can see that there cannot be a Nash equilibrium in which every generator is hedged to the maximum level unless, the spot price, when every generator is producing at its maximum level, exceeds the marginal cost by a sufficient margin. That margin decreases rapidly in the number of firms and in the degree of market power $\overline{\alpha}$. The larger the number of oligopolistic firms and the smaller their market power the greater the likelihood that a full-hedging equilibrium exists. We can summarize this conclusion as follows:

Proposition 2 *Under the assumptions of linear residual demand and constant marginal cost, and uncertain demand with the property that the profit-maximizing level of output of each firm is independent of the realization of the demand parameters, given a set of n identical generators, and assuming that firms play a Cournot game in quantities in the spot market and a Cournot game in hedge levels in the hedge market, then there is no rational-expectations equilibrium in pure strategies in the hedge market unless the expected future wholesale spot price when all generators produce at their maximum output exceeds the marginal cost by the following margin:*

$$p^{max} - c > \frac{\overline{\alpha}(q^{max} - q^{min})}{n(n-1)}$$

3.2 Hedge price dependent on firms' hedge level

For completeness, let's now consider the final case in which the traders are assumed to be able to observe the hedging level of all the generators with market power, so that the hedge price can perfectly track the expected future spot price (the standard "no arbitrage" assumption). We can write the expected profit as follows:

$$
\begin{aligned}
\pi_i(x_i|X_{-i}) &= (p(X) - c_i)q_i(X, x_i) + (f - p(X))x_i \\
&= \alpha\left(s(X) + \frac{\overline{c} - c_i}{\alpha}\right)\left(s(X) + x_i + \frac{\overline{c} - c_i}{\alpha}\right)
\end{aligned}
$$

The expected profit has a unique interior maximum since $s(X)$ is a linear function of x_i with a coefficient between -1 and zero. From the first order condition for x_i we find that the optimal hedge position for each generator is:

$$x_i(X) = (n-1)\big(s(X) + (\overline{c} - c_i)/\overline{\alpha}\big)$$

Using (7) we have that the optimal quantity choice for each generator is:

$$
\begin{aligned}
q_i(X) &= s(X) + (\overline{c} - c_i)/\alpha + x_i(X) \\
&= n\big(s(X) + (\overline{c} - c_i)/\alpha\big)
\end{aligned}
$$

Hence it follows that a weighted average of the output of each generator is:

$$E(\alpha q_i) = n(\overline{\alpha}s(X) + (\overline{c} - c_i)) = \overline{\alpha}nx_i/(n-1)$$

This proves that in the Nash equilibrium, each firm chooses to be hedged a fixed proportion of a weighted average of its output, with the proportion increasing as the number of firms in the market increases.

$$x_i(X) = \left(1 - \frac{1}{n}\right)\frac{E(\alpha q_i(X))}{\overline{\alpha}}$$

Thus we have proven the following (slightly different to the result in [7]):

Proposition 3 *Suppose we have a Cournot oligopoly of capacity-unconstrained firms with possibly varying marginal costs and capacities, facing a capacity-constrained fringe of firms and a linear demand schedule, with the property that the volume of demand at the average marginal cost is constant. Each firm will choose to be hedged the same proportion of a weighted-average of its output:* $1 - \frac{1}{n}$.

4   CONCLUSION

Electricity market regulators are very concerned about the potential for large generators to exercise market power and have developed a variety of approaches for assessing the likely impact of a change in the market on the future exercise of market power. But these approaches take the level of hedge contracting of genera-

tors as exogenous. In reality, the level of hedge contracting of a generating firm is itself dependent on factors such as the market structure. A change in the market structure could be expected to change both the level of hedge contracting and the resulting competition in the wholesale spot market. We need a model of the actions of generators in both the forward and the spot markets.

The previous literature on the equilibrium level of hedging in an electricity market has made a "no arbitrage" assumption that hedge prices are equal to expected future spot prices. This implicitly assumes that traders in the forward markets have detailed knowledge of the hedge position of dominant firms – information which is unlikely to be available to hedge traders. Instead we argue that it is more appropriate to assume that hedge prices are independent of hedging decisions.

We show that under this assumption, in a market dominated by a firm with a high degree of market power there may be no equilibrium hedge position in pure strategies. We argue that this prediction reflects the patterns of outcomes observed in the South Australian region of the Australian National Electricity Market which has witnessed substantial fluctuation in the level of hedge cover and in the volatility of prices, combined with a low level of liquidity.

The model shows that as the number of firms in the market increases, there arises an equilibrium in which all the firms choose to be fully hedged. Conversely there is a risk that even a small reduction in the number of firms in the market may have a large impact on the hedging decisions of the dominant generators.

This paper suggests that competition regulators need to be particularly concerned about horizontal mergers of electricity generators. A merger which reduces wholesale market competition may result in the merging firms choosing to be substantially unhedged following the merger. However, this paper has not specifically focused on analyzing the consequences of mergers. Further research is necessary identify the conditions under which even relatively small mergers will have a significant effect on the hedge market.

This paper has focused on the special case of linear demand and constant marginal cost in order to derive closed-form analytic results. It would also be desirable to extend this model to a more general framework of cost and demand to verify these results and further clarify the range of conditions under which these results could be expected to hold.

REFERENCES

[1] P. Twomey, R. Green, K. Neuhoff and D. Newbery, "A Review of the Monitoring of Market Power", Cambridge Working Papers in Economics, CWPE 0504, 2005

[2] B. Allaz and J.-L. Vila, "Cournot competition, forward markets and efficiency", Journal of Economic Theory, vol. 59, pp. 1-16, 1993.

[3] P. Mahenc and F. Salanié, "Softening competition through forward trading", Journal of Economic Theory, Vol. 116, pp. 282-293, 2004

[4] R. Green, "The Electricity Contract Market in England and Wales", Journal of Industrial Economics, Vol. 47, No. 1, pp. 107-124, 1999.

[5] P. Holmberg, "Strategic Forward Contracting in the Wholesale Electricity Market", The Energy Journal, Vol. 32, No. 1, 2011

[6] J. J. Sánchez, D. W. Bunn, E. Centeno, and J. Barquín, "Dynamics in Forward and Spot Electricity Markets", IEEE Transactions on Power Systems, Vol. 24, No. 2, pp. 582-591, 2009.

[7] B. Willems, "Cournot Competition, Financial Option Markets and Efficiency", Centre for the Study of Energy Markets, CSEM WP 139, March 2005

[8] J. S. Hughes and J. L. Kao, "Strategic forward contracting and observability", International Journal of Industrial Organization, Vol. 16, pp. 121-133, 1997

[9] J. L. Ferreira, "The Role of Observability in Futures Markets", Topics in Theoretical Economics, Vol. 6, No. 1, Article 7. Available at: http://www.bepress.com/bejte/topics/vol6/iss1/art7

[10] D. Newbery, D., "Predicting Market Power in Wholesale Electricity Markets", EUI Working Papers, RSCAS 2009/03, 2009.

[11] Australian Energy Regulator, "State of the Energy Market 2009", ISBN 978-1-921581-40-3, 2009.

[12] ACIL Tasman, "Competition in South Australia's retail energy markets", report prepared for the Essential Services Commission of South Australia, 24 June 2010

[13] .D. Biggar and M. Hesamzadeh, "The TC-PSI indicator for forecasting the potential for market power in wholesale electricity markets", submitted to Energy Policy, 2011.