

Market Power in the Wholesale Electricity Spot Market in Alberta, Canada

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Abstract

This paper examines market power in the wholesale electricity spot market in the Canadian province of Alberta. The characteristics of electricity markets and the structure of the post-regulation industry suggest that there is the potential for the exercise of market power by electricity generators. Using data for the period from 1998 to 2002, I estimate a parameter indicating the degree of competitiveness in the market, and find it is consistent more with competition than with the exercise of market power. I conclude that the market design and industry restructuring have been successful in constraining the strategic behaviour of firms.

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1 Introduction

In the past fifteen years, governments in North America, Europe and Australia have started deregulating their electricity industries, and many others are considering such a policy. Generally, the objective has been to reduce prices for consumers, to encourage new investment and to reduce the government's costs of regulating the industry. In most cases, a competitive market has replaced the regulated rate of return pricing systems under which electricity generators operated in the past. The purpose of these markets is to encourage efficient generation of electricity and to provide appropriate price signals to potential entrants. Historically, however, electricity industries have been typified by a small number of vertically integrated incumbents. This concentration in electricity generation raises the possibility of firms exercising market power. In view of this, governments must carefully consider the post-regulatory industry structure and the design of market mechanisms.

The experience of Alberta, Canada, reflects many of the complex decisions involved in deregulation. Alberta began restructuring its electricity industry in 1995, and its wholesale electricity market has been nearly fully deregulated since 2001. The Alberta case can thus provide insight into the policy considerations of deregulation and the subsequent outcomes in the marketplace, which is important for other markets now considering deregulation.

This paper considers whether firms in the Alberta wholesale electricity market have exercised market power since generation was deregulated. As minimizing potential market power was an explicit objective of the wholesale market design and the industry restructuring, resolving this question would provide a measure of the success of these policy choices. Furthermore, evidence that firms can and have exercised market power would have significant consequences for the Alberta economy and the current Alberta government, which has made deregulation of the electricity industry a key political objective.

Using data from 1998 to 2002, I employ a method developed by Bresnahan (1982) to estimate a parameter indicating the degree of market power. Estimates of the parameter

are less than what is predicted by the Cournot model of oligopoly, which has been commonly used to analyze electricity markets. The results are closer to the perfectly competitive outcome, suggesting that the industry restructuring has been successful in minimizing the exercise of market power.

The paper is organized as follows: Section II discusses market power in the context of electricity markets. Section III summarizes the deregulation process in Alberta and provides an overview of the industry structure during the period studied. In Sections IV and V, I develop the empirical framework and discuss the data used to estimate the degree of market power. Section VI presents the results of the empirical analysis and Section VII concludes.

2 Market Power in Electricity Markets

Electricity industries can be divided into four segments: generation, transmission, distribution and retail services (Joskow (1997)). Electricity can be generated using a variety of technologies, including oil-, coal- and natural gas-fired thermal generation plants, hydroelectric dams, and wind farms. Generated power is transmitted by high-voltage power lines to utilities, which convert the power to lower voltages suitable for distribution to residential, commercial and industrial consumers. These utilities may also provide retail services such as metering and billing to these consumers. Transmission and distribution are considered natural monopolies, but generation and retail services are not (Newbery (1995)). In most cases, generation has been the first segment of the industry to be deregulated, and it is in this market where most studies have considered market power.

A firm exercises market power through strategic behaviour that affects the market-clearing price and quantity. Typically, this behaviour involves reducing its output or raising its price (Borenstein et al. (2000)). This is more clearly expressed in the classic model of Cournot competition, under which firms choose their levels of output knowing that their strategy and the strategies of other firms will affect the market equilibrium.

Shapiro (1989) shows that a firm's profits are maximized under Cournot when the following condition holds:

$$\frac{P(Q) - c_i(q_i)}{P} = \frac{s_i}{\eta}, i = 1, \dots, n, \quad (1)$$

where $P(Q)$ is the industry demand function, Q is total output, $c_i(q_i)$ is the i th firm's marginal cost, s_i is the i th firm's market share, η is the price elasticity of demand and n is the number of firms.¹ From (1), it follows that each firm's market power is directly proportional to its share of the market and inversely proportional to the price elasticity of demand. Moreover, Cournot is socially inefficient, since all firms are producing at levels where the market price is greater than their marginal cost. Under a monopoly or collusive oligopoly, price-cost mark-ups will depend solely on the price elasticity of demand; at the other extreme of perfect competition, $P(Q) = MC_i(q_i)$ and hence the price-cost mark-up is zero. The Cournot oligopoly outcome thus lies somewhere between perfect competition and monopoly. It is clear that if the industry is dominated by a few firms with large market shares or if demand exhibits low price elasticity, then firms behaving as Cournot oligopolists can unilaterally raise the market price above their marginal cost of production by reducing their output.

Although Cournot has often been used to analyze electricity markets², it is not clear whether it is the best model of the behaviour of electricity generators, as generally firms can also choose the prices at which they offer electricity. This suggests that the Bertrand model of oligopoly may be more applicable, in which case the market price would be expected to be closer to the competitive outcome. Borenstein et al. (1999), however, contend that Bertrand competition is inappropriate because it assumes that each firm can expand output sufficiently to serve the entire market, which is unlikely to be the case in electricity markets. Indeed, models of Bertrand competition with capacity constraints may have equilibria that are closer to the Cournot outcome (see Tirole (2002), p. 215). Klemperer and Meyer (1989) provide a solution to a model of oligopoly in which

¹The cost function is assumed to be non-decreasing in output.

²See Borenstein et al. (1999) for a list of studies of electricity markets that apply Cournot.

firms choose a “supply function” relating their quantity of output to the market price, which is a closer fit for the nature of competition in this case. They find that “quantity-setting models” (i.e. Cournot) may be more appropriate when marginal cost curves are steeper relative to demand, whereas “price-setting models” (i.e. Bertrand) describe competition better when marginal costs are flatter. In general, industry marginal cost curves in electricity generation are flat along most of their range, but become increasingly inelastic as capacity constraints are approached. In view of this, it is likely that Bertrand competition is a better approximation when there is spare generation capacity, but the outcome approaches that of Cournot as production approaches capacity constraints (Newbery (2002)). This would imply that Cournot describes the behaviour of firms during peak demand periods.

In electricity markets, generators can exert market power through either physical or economic withholding. In most market designs, firms submit a schedule of price-quantity “blocks” reflecting how much electricity they are willing to generate at different prices. The system controller then dispatches capacity in increasing order of cost, and the marginal block (i.e. the last block dispatched to meet demand) sets the market price. If a generator physically withholds a block from the market by not offering it, the controller may have to dispatch higher-priced generation in order to meet demand, resulting in a higher market price. Assuming the generator has submitted other, lower-priced blocks and the increased profit on these blocks from the rise in price is greater than the profits lost by not offering the withheld block, the generator will increase its total profits. Similarly, a generator may employ economic withholding by offering a block at a price sufficiently high that it will not be dispatched. Again, other, possibly higher-priced blocks may have to be dispatched, with the same result. In both cases, assuming that the withheld blocks would have been dispatched had they been offered at marginal cost, the generator’s behaviour will result in a higher market price.

The profitability of withholding depends on the nature of the industry supply relation. If, for example, a number of firms submit blocks of electricity at similar prices in the range where supply and demand are expected to balance, withholding output may

not be profitable, as the price may not rise sufficiently to compensate the firm for the revenues lost from withholding output. If supply is inelastic, however, such as when demand rises close to capacity, then withholding may be a profitable strategy (Borenstein et al. (1999)).

The responsiveness of demand to price may mitigate the effects of market power. If demand is price elastic, a reduction in quantity will result in a proportionately smaller increase in the market price. Wholesale electricity markets, however, tend to be very price inelastic, since residential, commercial and small industrial consumers are generally not exposed to the market price in real time. Only large industrial consumers participating directly in the market can reduce their loads in response to changes in the wholesale market price. This lack of price responsiveness implies that withholding capacity may be highly profitable for a firm, as it could result in an increase in price without a significant loss of market share.

The foregoing considers only the unilateral exercise of market power, but electricity generators may be capable of exercising market power through implicit or explicit collusion. Given the concentration of firms, the repeated and frequent interaction in the market, the predictability of demand, the similarity of cost structures, and the ability to observe prices (and in some markets, offers) *ex post*, the Folk theorems imply that tacit collusion may be sustainable.³ Thus, the exercise of market power in electricity markets may be the result of either unilateral and multilateral actions of market participants. As Borenstein et al. (1999) note, however, models of collusion do not provide much insight into how to identify the exercise of market power through collusive behaviour. Thus, the hypothesis that generators may engage in collusion is not pursued here.

A number of studies have found that the ability to exercise market power is greater in highly concentrated markets and when demand is high and inelastic, which is an accordance with the theory developed above. Brennan and Melanie (1998) simulate the deregulated electricity market in Australia and find there is potential for the three dominant firms in New South Wales to exert market power, particularly during peak

³See Tirole (2002), p. 245-250, for a general discussion of the factors affecting the sustainability of tacit collusion in the context of supergame theory.

hours. Similarly, Green and Newbery (1992) consider the British market and find that early in the deregulation process the two dominant generators possessed “very considerable” market power. Borenstein and Bushnell (1999) also find that there is potential for market power in the California market.

Other studies have estimated market power retrospectively. Wolfram (1999) examines the behaviour of firms in the British market during 1993 and 1994 and finds that price-cost mark-ups, while significant, were below the levels predicted by the Cournot and supply function models of oligopoly. Both Borenstein et al. (2000) and Puller (2002) find evidence of market power in California during the period from 1998 to 2000, primarily during high demand periods. Similarly, Joskow and Kahn (2002) find a large difference between actual prices and simulated benchmark prices in California during June, July and August, 2000, which they attribute in part to market power exercised by suppliers withholding supply during peak hours. Harvey and Hogan (2001a,b,c) challenge this finding, however, contending that a lack of publicly available data introduces error into the calculations, making inference unreliable.

The exercise of market power in electricity markets can have significant effects on consumer welfare, economic efficiency and the environment. As electricity demand is nearly price inelastic, the exercise of market power will result in higher prices and a transfer of economic rents from consumers to producers in the form of higher profits. Moreover, as demand response to higher prices is minimal in the short-term, no inefficiency will arise from underconsumption, but less efficient production may have to be substituted for withheld capacity (Borenstein et al. (2000)). Mansur (2001) shows that this substituted generation may also have higher air pollution emissions, so the exercise of market power may also lead to an increase in pollution.⁴ In the long term, higher prices in the wholesale market may also distort investment incentives. As Borenstein et al. (2000) note, high prices caused by market power may lead to inefficient investment in new generation and a reduction in investment by firms on the demand side. Despite these effects, however, a market subject to limited market power may still be preferable

⁴Mansur (2001) also notes that in some cases, less polluting generation may be substituted for withheld capacity, with the result that air quality may actually *improve* if firms exercise market power.

to regulation. Newbery (1995) points out that if the costs of the exercise of market power are less than the costs of inefficient investment under a regulated regime, then an imperfectly competitive market achieves higher total welfare.

3 The Alberta Electricity Industry

In Alberta, generation and retail services have been opened to competition, but transmission and distribution remain under government regulation.⁵ Prior to deregulation, three vertically-integrated utilities, TransAlta Utilities, Alberta Power and Edmonton Power, dominated Alberta's electricity industry. These utilities owned most of Alberta's transmission system and supplied electricity to municipal utilities and their own franchise areas. The largest, TransAlta, owned over 50% of the province's generation capacity, with the two others each holding approximately 20% (Daniel et al. (2003)). All generation was centrally dispatched based on the average cost of production, and generators received a regulated rate of return based on their average costs.

The creation of the wholesale market for electricity in 1996 was one of the first steps in the deregulation process. This market is managed by the Power Pool of Alberta, which is also responsible for dispatching generation and maintaining the stability of the electricity network (Government of Alberta (2002)). All electricity traded in Alberta is sold through this market, and it sets the spot price for electricity for every hour of the day. A day ahead, generators submit a schedule for each hour indicating at what prices they will supply different quantities of electricity.⁶ Similarly, utilities and industrial customers submit bids to reduce their load when the market price rises above their bid price. The Market Administrator sorts offers and bids by price to create a "merit order." On the day of production, the System Controller moves up and down the merit order to dispatch supply and demand blocks as system load (i.e. electricity demand) changes.

⁵Daniel et al. (2003) provide a detailed history of the Alberta electricity industry and the deregulation process.

⁶Generators are permitted to restate the quantity of submitted offers. Generally, capacity that is not economic to run in a given hour at forecasted prices will be restated downwards, resulting in a left shift of the day-ahead curve (Power Pool of Alberta (2002)). Also, capacity may be restated in order to meet reserve requirements.

The price of the marginal block - the last bid or offer that must be dispatched - sets the System Marginal Price (SMP) every minute. At the end of the hour, a time-weighted average of the marginal prices is used to calculate the “Pool price” for that hour. Utilities and industrial customers pay this price to generators for each megawatt-hour (MWh) of electricity consumed.

The change from a regulated regime to a competitive market raised two issues (Daniel et al. (2003)). Plants built under regulation were constructed under the assumption that their output would earn the average cost of generation and a legislated rate of return. With the change to marginal cost pricing, newer plants would be earning below their average costs, leaving the owners with high “stranded” fixed costs. On the other hand, the owners of older, fully depreciated plants would earn returns far above what they would in the regulated environment. The government of Alberta decided that residents of the province should retain these residual benefits but also bear the stranded costs. Furthermore, as generation remained highly concentrated, there was a risk of the three dominant generators exercising market power in the wholesale market.

To address this, the provincial government introduced “legislated hedges,” which protected previously regulated units from the Pool price. Owners of these plants continued to sell the output through the wholesale market, but under the hedges, they received returns similar to those earned under regulation.⁷ As the regulated units accounted for most of the generation capacity of the three dominant generators, very little of their output was exposed to the Pool price and hence they had little incentive to exercise market power. London Economics Inc (1998) concludes that the hedges were successful in this respect, and prices in the wholesale market did remain low during the period when the hedges were in effect. However, London Economics Inc (1998) also found that the hedge structure distorted Pool prices downwards and hence reduced incentives for new investment. Indeed, despite increasingly tight supply, there was very little new investment in generation capacity during the period from 1996 to 2001.⁸

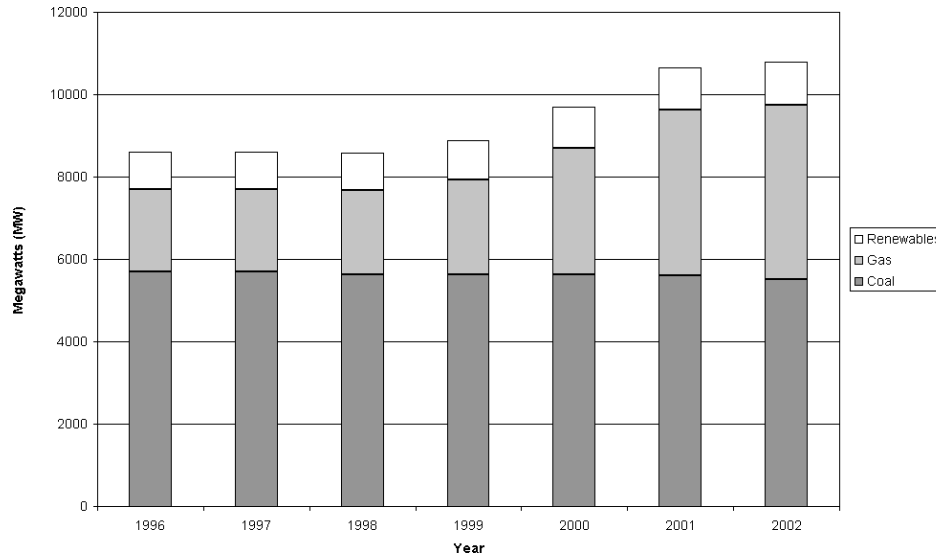
⁷See Government of Alberta (1998) for a detailed explanation of the hedge structure.

⁸Daniel et al. (2003) argue that low Pool prices cannot provide a sufficient explanation for the lack of investment and ascribe it to uncertainty over the path of deregulation.

To eliminate the distortion imposed by the hedge structure without creating opportunities for the dominant firms to exercise market power, the government required owners of regulated units to sell the rights to the future production of those units. Output from regulated units was sold at auction under the terms of so-called Power Purchase Arrangements (PPAs). The successful bidders obtained the right to offer the output into the wholesale market, and in exchange, PPA purchasers would pay the owners of the regulated units for their output under formulae calculated to give a return similar to that which would have been obtained under regulation. Mitigating market power was an explicit objective of the PPA auction, and the auction rules were designed to minimize the chance of firms obtaining generation portfolios that would permit them to exercise market power (Charles Rivers Associates Inc. (1999)). The PPAs took effect on January 1, 2001, and apply for periods of three to twenty years, depending on the expected life of the unit. The auction was held in August 2000, but only eight of the twelve PPAs, constituting 66% of the 6425 MW of generation capacity available, were sold (Daniel et al. (2003)). The Balancing Pool of Alberta, an organization set up to manage the financial aspects of deregulation, assumed responsibility for offering the unsold capacity into the wholesale market.

While the PPA auction permitted new entry into the generation market by power marketers, there has also been a significant expansion of generating capacity in Alberta in recent years (Figure 1). Since 1996, almost all of the new generation has been gas-fired, reflecting the lower investment required for plants of that type (Government of Alberta (2002)). Total capacity grew by over 9% in both 2000 and 2001, and by approximately 22% overall between 2000 and 2002. Alberta can also import or export power through connections to the neighbouring provinces of British Columbia and Saskatchewan. The BC and Saskatchewan interconnections are quite small in relation to Alberta's installed capacity; the former has a capacity of 800 MW and the latter 150 MW. At the end of 2002, Alberta had a total capacity of 11,751 MW, but only approximately 10,200 MW is available to the Alberta electrical grid (Government of Alberta

Figure 1: Alberta Installed Generation Capacity by Type, 1996-2001. Source: Alberta Energy and Utilities Board (2002).



(2002)).⁹

Over 60% of Alberta’s generation capacity continues to be owned by the three major utilities (Government of Alberta (2002)), but as a result of the PPA auction and new entry, concentration in the wholesale market is much lower, as Table 1 shows.

The demand for electricity can be decomposed by sector (Figure 2). Industrial demand is a little over half of the total, and its share has been rising during the the past ten years. Residential demand has grown in proportion to Alberta’s population and has remained at a relatively constant share of around 15%. The shares of commercial and farm demand have been decreasing, but this likely reflects the rapid growth of industrial demand.¹⁰

Electricity demand is highly variable depending on the season, day of the week and time of day. Figure 3 reflects the seasonality of electricity demand and the overall growth in electricity demand over the period due to population and economic growth. Demand peaks in winter when there is greater demand for lighting, but there is also a smaller peak in summer, likely due to demand for air conditioning. Unlike many other

⁹The unavailable capacity consists of generation for in-house industrial purposes.

¹⁰Commercial demand includes street lighting and industrial demand includes transportation.

Table 1: Approximate Generating Shares of Participants in Alberta Wholesale Market, 2002. Source: Power Pool of Alberta (2002).

| Participant | Capacity (MW) | Share |
|-----------------------|----------------------|--------------|
| Balancing Pool | 2156 | 19.2% |
| Participant 2 | 1386 | 12.3% |
| Participant 3 | 1381 | 12.3% |
| Participant 4 | 1310 | 11.6% |
| Participant 5 | 829 | 7.4% |
| BC Tie Line | 800 | 7.1% |
| Participant 7 | 743 | 6.6% |
| Participant 8 | 445 | 4.0% |
| Participant 9 | 345 | 3.1% |
| Participant 10 | 310 | 2.8% |
| Participant 11 | 296 | 2.6% |
| Participant 12 | 240 | 2.1% |
| Participant 13 | 205 | 1.8% |
| Saskatchewan Tie Line | 150 | 1.3% |
| Other | 656 | 5.8% |
| Total | 11252 | |

Figure 2: Alberta Electricity Demand by Sector, 1992-2001. Source: Alberta Energy and Utilities Board (2002).

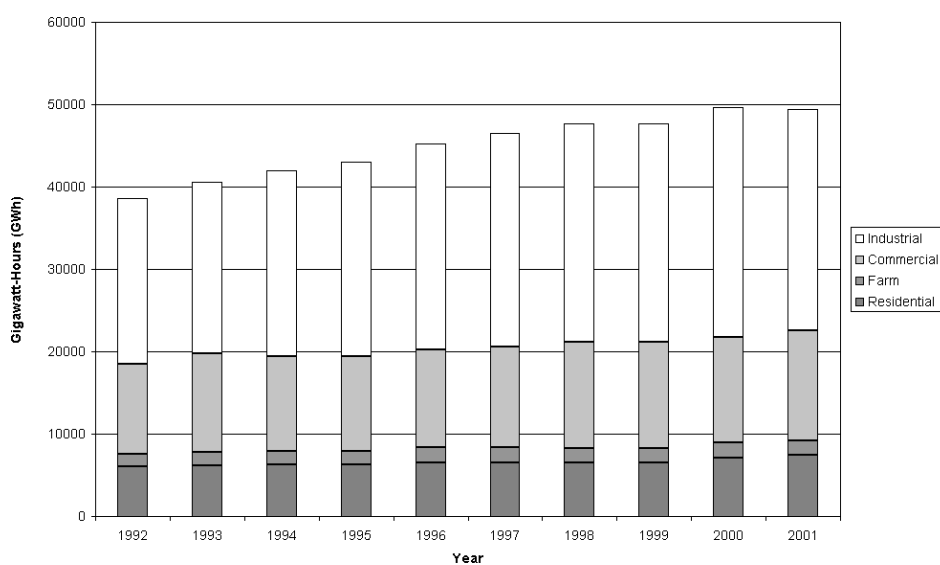
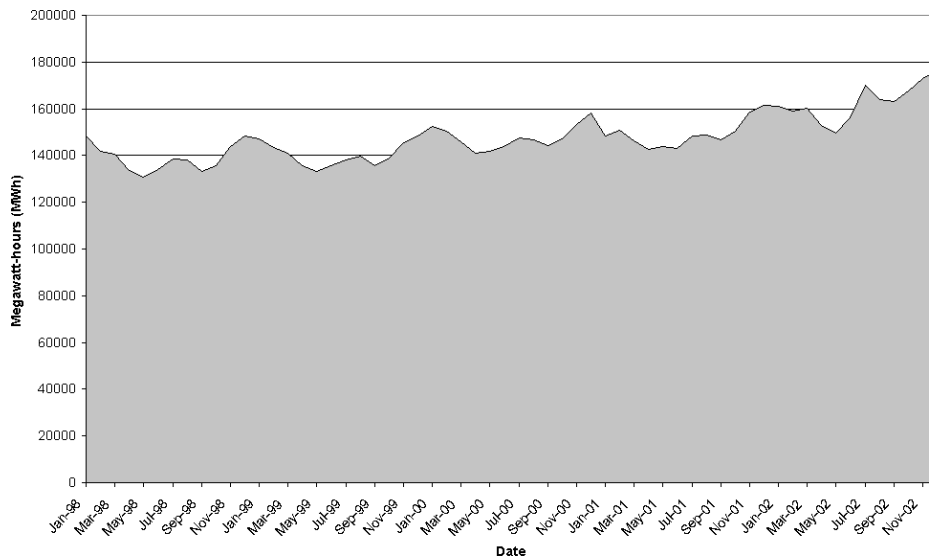


Figure 3: Total Alberta Electricity Demand by Month, 1998-2002. Source: Power Pool of Alberta Historical Data.



markets, almost all of Alberta’s homes are heated by natural gas, hence heating demand is minimal.¹¹ Examination of historical load data shows that during the day, demand reaches a minimum during early morning hours and a maximum in the evening. More electricity is demanded on weekdays than weekends, but demand does not otherwise vary significantly during the week. As in most electricity markets, price elasticity of demand is very low, as residential, farm and commercial customers will only adjust their use with a significant lag. Large industrial customers, however, may be able to vary their use of electricity depending on the spot market price. The Power Pool of Alberta (2002) notes that in Alberta, load grew increasingly responsive to price spikes throughout 2001.

To my knowledge, only London Economics Inc (1998) has formally considered potential market power in the Alberta generation market, finding that in the absence of the legislated hedges, the three major utilities would have had significant market power due to their concentration of generation capacity. Although concentration has since decreased, firms may still be capable of exercising market power due to the low price

¹¹98% of residences in Alberta are heated by natural gas and only 1% by electricity. Of total residential electricity demand, 1.87% is used for heat, 1.50% is for domestic hot water, 4.5% is for Heat Recovery Ventilators, 0.38% for air conditioning and 91.7% for appliances and lighting (Aydinalp et al. (2000)).

elasticity of demand and the inelasticity of supply during peak periods. The question of whether this is in fact the case can be answered to some extent by an estimate of the competitiveness of the market.

4 Empirical Framework

Bresnahan (1982) considers a general model of demand in which exogenous variables both shift and rotate the demand curve. He argues that if firms behave as price takers, then changes in the price elasticity of demand (i.e. rotations of the demand curve) will not affect their behaviour and the market equilibrium will be unchanged. However, if the firms are exercising market power, then they will adjust their strategic variables and the market will move to a new equilibrium. He shows that by estimating a system of equations consisting of the market demand function and the industry supply relation, one can obtain a parameter indicating the degree of market power.

Following this analysis, I assume the following general model of electricity demand:

$$Q_t = D(P_t, Y_t, \alpha) + \varepsilon_t, \quad (2)$$

where Q_t is the quantity of electricity demanded (MW), P_t is the price of electricity (\$/MW), Y_t is a vector of exogenous variables that shift and rotate the demand curve, α is the vector of parameters to be estimated and ε is the econometric error term. Further assume that n firms have identical marginal cost functions of the form:

$$MC_i(q_{it}) = c_i(q_{it}, W_t, \beta) + \eta_t, i = 1, \dots, n, \quad (3)$$

where q_{it} is firm i 's output in period t , W_t is a vector of exogenous variables that shift the marginal cost curve and β is the vector of coefficients. A profit-maximizing firm will set output q_t such that marginal revenue is equal to its marginal cost:

$$P_t(Q_t) + \tilde{\lambda}_i \frac{\partial P}{\partial Q} q_{it} = MC_i(q_{it}), i = 1, \dots, n, \quad (4)$$

where $\tilde{\lambda}_i$ is a parameter reflecting the firm's degree of market power and $Q_t = \sum_{i=1}^n q_i$. If a firm is a Cournot oligopolist, then $\tilde{\lambda}_i = 1$. If the firm is a price-taker, then $\tilde{\lambda}_i = 0$. Taking the average across all n firms, obtain

$$P_t = -\frac{\partial P}{\partial Q} Q_t \sum_{i=1}^n \frac{\tilde{\lambda}_i q_{it}}{nQ_t} + MC(Q_t), \quad (5)$$

where

$$MC(Q_t) = \frac{1}{n} \sum_{i=1}^n MC_i(q_{it}). \quad (6)$$

For simplicity, let

$$\lambda = \sum_{i=1}^n \frac{\tilde{\lambda}_i q_i}{nQ}$$

and obtain the industry supply relation:

$$P_t = -\lambda \frac{\partial P}{\partial Q} Q_t + MC(Q_t). \quad (7)$$

The parameter λ is thus the market share weighted average of each firm's $\tilde{\lambda}$ parameter. It follows that if all firms are price-takers, $\lambda = 0$. In a Cournot oligopoly with n symmetric firms, $\lambda = \frac{1}{n}$. Thus, this parameter indicates the degree of market power exercised by firms in the industry.

To make the foregoing more tractable, consider the following log-linear version of equation (2):

$$Q_t = X_t' \alpha + \alpha_p P_t + \alpha_{pw} P_t WINTER_t + \varepsilon_t \quad (8)$$

P_t and Q_t are the price and quantity in each period, X_t is the vector of variables that shift demand and $WINTER_t$ is a dummy variable that takes the value of 1 during the months of January and December. Since these months are the peak demand periods, I expect industrial customers to be more responsive to price during the winter, and hence demand will be more price elastic.

As most of the generation in Alberta is coal- or gas-fired, fuel costs are likely to have the largest effect on marginal cost. Due to the abundance of coal in Alberta, fuel costs for coal-fired plants are low and stable (Government of Alberta (2002)). Firms operating gas-fired plants, on the other hand, must purchase fuel on the open market, in which they are assumed to be price-takers.¹² Other costs are not so easily observable. In particular, “ramping” generation output up or down affects maintenance costs, particularly with coal-fired plants, so some plants may not run unless prices are expected to remain sufficiently high to warrant bringing them online. Borenstein et al. (2000) note that opportunity costs also include foregone sales in other markets. In Alberta, generators may export power to neighbouring markets, but given the transmission constraints of the British Columbia and Saskatchewan interconnections, export opportunities are limited.

Based on the above, I assume the following log-linear industry marginal cost function:

$$MC(Q_t) = \beta_0 + \beta_1 Q_t + \beta_2 NATGAS + \eta_t. \quad (9)$$

From (8), obtain:

$$\frac{\partial P}{\partial Q} = \frac{1}{\alpha_p + \alpha_{pw} WINTER}.$$

Using this and equations (7) and (9), obtain:

$$P_t = -\lambda Q_t^* + \beta_0 + \beta_1 Q_t + \beta_2 NATGAS + \eta_t, \quad (10)$$

where

$$Q_t^* = \frac{Q_t}{\alpha_p + \alpha_{pw} WINTER}.$$

¹²In general, owners of natural gas-fired plants enter into long-term supply contracts or purchase forward contracts for natural gas to ensure stable fuel costs. However, the spot price of natural gas reflects their opportunity cost of production.

Following Bresnahan (1982), it is clear from the above that both the demand function (8) and the supply relation (10) are identified. Furthermore, $\hat{\lambda}$ is identified.

5 Data

To estimate the equations described above, I obtained data from a number of sources. Hourly data on Pool prices and load for the period 1998 to 2002 were obtained from the Power Pool of Alberta. For simplicity, daily indices of load and price were constructed from the hourly data. The daily load is the sum of the hourly loads, and the daily average price is the average of the hourly prices weighted by load in each hour.

In Alberta, the most appropriate index of natural gas prices is the AECO-C/NIT spot price, which is the price of most gas traded in the province. However, as data on the AECO-C/NIT price was unavailable for the entire period, I substituted the NYMEX Henry Hub daily spot price, adjusted by the daily US-Canada exchange rate.¹³ As the North American natural gas market is tightly integrated, these prices are highly correlated and it should be an appropriate proxy. It is clear from Figure 3 that the Pool price closely tracks the price of gas. This is to be expected given that gas plants often set the Pool price during peak hours (Market Surveillance Administrator (2003)).

As a proxy for lighting demand, I used the number of minutes of daylight in each day, which I calculated from sunrise and sunset times obtained from the United States Naval Observatory for the city of Calgary. Calgary is the largest city in Alberta and is located roughly in the middle of the most populated region of the province.

6 Results and Discussion

Table 1 shows the results of the Two Stage Least Squares (2SLS) estimation of the log-linear demand function 8 for the period 1998 to 2002 using the price of natural gas (NATGAS) as the instrument for the included endogenous variable P.¹⁴

¹³Data on natural gas prices and exchange rates were obtained from Datastream.

¹⁴Due to the presence of both heteroskedasticity and first order serial correlation, Heteroskedasticity and Autocorrelation Consistent standard errors are calculated in accordance with the procedure developed

Figure 4: Average Daily Pool Spot Price and Natural Gas Price, by Month, 1998-2002.
Source: Power Pool of Alberta and Datastream.

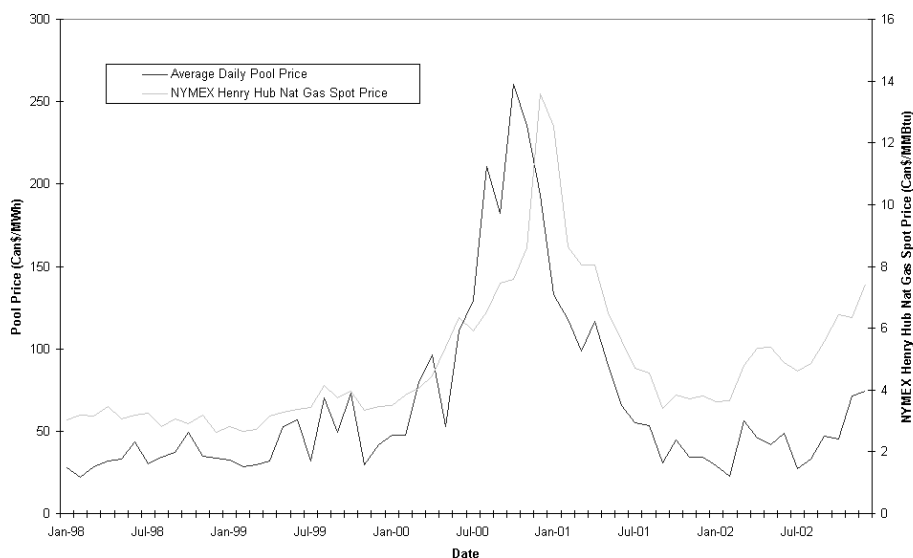


Table 2: Results of 2SLS Estimation of Demand Function for 1998 to 2002 (N=1826).
Dependent Variable: LOG(Q).

| Variable | Coefficient | Std. Error | t-Statistic | Newey-West HAC | |
|--------------------|-------------|--------------------------|-------------|----------------|-------------|
| | | | | Std. Error | t-Statistic |
| Constant | 12.9 | 0.0291 | 442 | 0.0480 | 268 |
| LOG(P) | -0.00533 | 0.00198 | -2.69 | 0.00357 | -1.49 |
| LOG(DAYLIGHT) | -0.161 | 0.00426 | -37.9 | 0.00644 | -25.0 |
| WEEKDAY | 0.0565 | 0.00143 | 39.5 | 0.00148 | 38.2 |
| AUGUST | 0.0348 | 0.00241 | 14.4 | 0.00409 | 8.50 |
| JULY | 0.0564 | 0.00261 | 21.6 | 0.00473 | 11.9 |
| JUNE | 0.0289 | 0.00269 | 10.7 | 0.00439 | 6.57 |
| WINTER | 0.0503 | 0.0115 | 4.37 | 0.0360 | 1.40 |
| LOG(P)*WINTER | -0.0128 | 0.00290 | -4.42 | 0.00960 | -1.34 |
| 1999 | 0.0110 | 0.00195 | 5.64 | 0.00370 | 2.96 |
| 2000 | 0.0709 | 0.00286 | 24.8 | 0.00589 | 12.0 |
| 2001 | 0.0775 | 0.00226 | 34.2 | 0.00462 | 16.8 |
| 2002 | 0.129 | 0.00195 | 66.1 | 0.00464 | 27.8 |
| R^2 | 0.850 | Sum of Squared Residuals | | 1.22 | |
| Adjusted R^2 | 0.849 | Durbin-Watson Statistic | | 0.579 | |
| S.E. of Regression | 0.0260 | F-statistic | | 868 | |

The results for the demand function are generally consistent with the *a priori* assumptions about the Alberta wholesale electricity market. All coefficients have the correct sign, and most are significant at very high levels.¹⁵ As all variables with the exceptions of the weekday, month and year dummies are in log form, the price elasticity of demand can be obtained from the coefficient of P. As expected, it is very low, implying that changes in the spot price have little effect on load. Similarly, demand is higher during the summer and winter months, reflecting the use of air conditioning in summer and electric lighting in winter. The coefficients of the year dummies are also consistent with the growth in electricity demand over the period. The coefficient of the interaction term (LOG(P)*WINTER) suggests that demand is more elastic during winter months, but as it is not statistically significant, this cannot be formally inferred.

Using these results, the variable Q* can be constructed and used to estimate the supply relation (Equation 10). Based on the Newey-West HAC standard errors, however, the coefficients of LOG(P) and LOG(P)*WINTER are not statistically significant at the 5% level, which immediately casts the reliability of the supply relation results into doubt. Nonetheless, the Ordinary Least Squares (OLS) results are provided in Table 2.

The estimates of the coefficients of the supply relation are generally consistent with the assumptions about the industry and with microeconomic theory. Given the log-linear form of the marginal cost function, the estimated constant and the estimated coefficient of Q imply that marginal costs increase sharply as load approaches capacity constraints. In general, one would expect the coefficient of the price of natural gas (NATGAS) to be one, but a one-tailed test of the null hypothesis, $H_0 : \beta_2 = 1$, against the alternative hypothesis, $H_a : \beta_2 > 1$, can be rejected at a 5% confidence level. Atkins and Chen (2002) note that most maintenance on Alberta generation occurs in the fall months, so a dummy variable (FALL) was included for observations in September, October and November to capture the effects of scheduled outages for maintenance. The estimated coefficient of this dummy is positive and statistically significant. The coefficients of the dummies for 2001 and 2002 are negative, reflecting the growth in capacity

by Newey and West (1987).

¹⁵An estimation of a linear form of the demand function yielded similar results.

Table 3: Results of OLS Estimation of Supply Relation, 1998-2002 (N=1826). Dependent Variable: LOG(P).

| Variable | Coefficient | Std. Error | t-Statistic | Newey-West HAC | |
|--------------------|-------------|--------------------------|-------------|----------------|-------------|
| | | | | Std. Error | t-Statistic |
| Constant | -29.6 | 2.96 | -10.0 | 4.39 | -6.74 |
| LOG(Q*) | -0.000137 | 2.11E-05 | -6.50 | 3.59E-05 | -3.82 |
| LOG(Q) | 2.65 | 0.248 | 10.7 | 0.368 | 7.21 |
| LOG(NATGAS) | 1.24 | 0.0376 | 32.9 | 0.0728 | 17.0 |
| FALL | 0.0955 | 0.0256 | 3.73 | 0.0491 | 1.95 |
| 1999 | 0.0407 | 0.0334 | 1.22 | 0.0571 | 0.71 |
| 2000 | 0.168 | 0.0452 | 3.71 | 0.0861 | 1.95 |
| 2001 | -0.272 | 0.0449 | -6.06 | 0.0747 | -3.64 |
| 2002 | -0.806 | 0.0511 | -15.8 | 0.0910 | -8.86 |
| R^2 | 0.612 | Sum of Squared Residuals | | 364 | |
| Adjusted R^2 | 0.610 | Durbin-Watson Statistic | | 0.797 | |
| S.E. of regression | 0.448 | F-statistic | | 358 | |
| Log likelihood | -1119 | | | | |

and the concomitant downward effect on prices. The coefficient of the 1999 dummy is positive but statistically insignificant, which reflects the lack of expansion during that year. By (10), the coefficient of Q^* is λ . It has the correct sign and is statistically significant, but its small magnitude implies that the exercise of market power was very slight during the period. While the hypothesis that the market is perfectly competitive ($\lambda = 0$) can be rejected, it is nonetheless well below the level expected if market participants behaved as Cournot oligopolists.

Given the changes in the industry structure since 1998, it is unlikely that firms' behaviour has been static during the period. In general, however, the results for 2001 and 2002 (Tables 4 and 5) are very similar to those from the entire five year sample.

Again, the coefficients have the anticipated signs and nearly all are significant at the 5% level. The price elasticity of demand is greater for these two years, which reflects the increased responsive of industrial loads to changes in price. Otherwise, the estimated coefficients for the demand function are similar in magnitude to the estimates for the five-year sample. The same holds for the supply relation, with the exception of the coefficient of the FALL dummy variable, which is now negative, but statisti-

Table 4: Results of 2SLS Estimation of Demand Function, 2001-2002 (N=730). Dependent Variable: LOG(Q)

| Variable | Coefficient | Std. Error | t-Statistic | Newey-West HAC | |
|--------------------|-------------|--------------------------|-------------|----------------|-------------|
| | | | | Std. Error | t-Statistic |
| Constant | 13.0 | 0.0482 | 269 | 0.0783 | 165 |
| LOG(P) | -0.0112 | 0.00336 | -3.33 | 0.00549 | -2.04 |
| LOG(DAYLIGHT) | -0.159 | 0.00742 | -21.4 | 0.0113 | -14.0 |
| WEEKDAY | 0.0534 | 0.00239 | 22.3 | 0.00246 | 21.7 |
| AUGUST | 0.0234 | 0.00432 | 5.42 | 0.00698 | 3.35 |
| JULY | 0.0563 | 0.00479 | 11.8 | 0.00906 | 6.22 |
| JUNE | 0.0209 | 0.00469 | 4.45 | 0.00704 | 2.96 |
| WINTER | 0.0884 | 0.0216 | 4.10 | 0.0480 | 1.84 |
| LOG(P)*WINTER | -0.0255 | 0.00542 | -4.70 | 0.0113 | -2.24 |
| 2002 | 0.0474 | 0.00255 | 18.6 | 0.00459 | 10.3 |
| R^2 | 0.737 | Sum of Squared Residuals | | 0.574 | |
| Adjusted R^2 | 0.733 | Durbin-Watson Statistic | | 0.565 | |
| S.E. of regression | 0.0282 | F-statistic | | 239 | |

Table 5: Results of OLS Estimation of Supply Relation, 2001-2002 (N=730). Dependent Variable: LOG(P)

| Variable | Coefficient | Std. Error | t-Statistic | Newey-West HAC | |
|----------------|-------------|--------------------------|-------------|----------------|-------------|
| | | | | Std. Error | t-Statistic |
| Constant | -30.5 | 4.46 | -6.84 | 6.78 | -4.49 |
| LOG(Q*) | -0.000284 | 6.42E-05 | -4.43 | 1.14E-04 | -2.50 |
| LOG(Q) | 2.70 | 0.370 | 7.28 | 0.563 | 4.80 |
| LOG(NATGAS) | 1.27 | 0.0492 | 25.9 | 0.0813 | 15.7 |
| FALL | -0.0650 | 0.0387 | -1.68 | 0.0615 | -1.06 |
| 2002 | -0.534 | 0.0367 | -14.5 | 0.0630 | -8.47 |
| R^2 | 0.568 | Sum of Squared Residuals | | 126 | |
| Adjusted R^2 | 0.566 | Durbin-Watson statistic | | 0.813 | |
| Log likelihood | -393 | F-statistic | | 238 | |

cally insignificant. This change may reflect the Power Pool's improved scheduling of maintenance of generation units in order to reduce the effect on Pool prices. In this sub-sample, the estimate of λ is greater than that for the entire sample, but it is still well below the level predicted by Cournot.

Overall, these results suggest that the exercise of market power has been very limited, but they must be interpreted with some caution. Besides the econometric problems described above, Corts (1999) argues that the methodology developed by Bresnahan (1982) may underestimate the degree of market power. Furthermore, as Borenstein et al. (2000) point out, methods of estimating market power at the market level capture all inefficiencies in the market, not just the exercise of market power. Thus, these results may not be an accurate reflection of market power in the Alberta wholesale market.

7 Conclusions

The foregoing has considered both the potential for and exercise of market power in the Alberta wholesale electricity market. Although the characteristics of electricity generation, the structure of the Alberta industry and the experience in other markets would suggest that there is potential for the exercise of market power, the empirical results imply that firms have not exercised or have not been successful in exercising market power during the period studied. This suggests that the legislative hedges employed until 2001 were sufficient to remove incentives to engage in strategic behaviour aimed at raising market prices. Furthermore, it would appear that the dilution of market shares through the PPA auction has been successful in limiting market power since the elimination of the hedges.

Clearly, however, further study is required. Given the drawbacks of the empirical technique employed here, one strategy would be to simulate competitive benchmarks using firm level data as other authors have done for the California and British markets. The feasibility of such a study is constrained by the availability of data, but it is the obvious next step towards a robust estimate of market power in Alberta.

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