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Oligopoly Equilibria in Electricity Contract Markets

James Bushnell

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UCEI

University of California Energy Institute

2547 Channing Way
Berkeley, California 94720-5180
www.ucei.org

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Abstract

The competitive implications of the ability of firms to trade in transparent forward markets has received considerable attention in the academic literature. These implications have not had much impact on policy however. This paper examines the implications of forward contracting on oligopoly environments by extending the model of Allaz and Vila to an environment with multiple firms and increasing marginal cost. Estimates of key parameters of this model are taken from existing electricity markets to predict the market impact of one round of public contracting, such as those seen in auctions for retail provision and resource procurement. The results imply that, when forward contracts are present, the importance of supplier concentration is greatly magnified relative to other determinants unilateral market power such as demand elasticity.

*University of California Energy Institute. 2547 Channing Way, Berkeley, CA 94720. Email: Bushnell@Haas.Berkeley.edu.

1 Introduction

Under traditional competition policy, the evaluation of horizontal market power begins with an assessment of horizontal structure. Relatively simple measures of horizontal concentration still play an important role. Many anti-trust authorities utilize concentration measures to define 'safe-harbor' thresholds for mergers. Proposed mergers that do not violate these thresholds will likely receive considerably less scrutiny. The U.S. Federal Energy Regulatory Commission (FERC), which has jurisdiction over wholesale electricity markets, utilizes concentration measures in its analysis of mergers and for the approval of 'market-based rates' for individual electricity producers (Bushnell, 2005).

In its merger guidelines, the U.S. Department of Justice utilizes a measure of concentration based upon the Hirschmann-Herfindahl Index (HHI), which is the sum of the squared market shares of each firm. Historically, these guidelines have strongly influenced competition policies at other agencies, such as the Federal Trade Commission (FTC) and FERC. Much of the intellectual grounding for the HHI comes from its relationship to the Cournot model of oligopoly. Under an assumption of Cournot competition, the Lerner Index, which measures the price-cost margin divided by price, is related to the HHI. In a Cournot equilibrium, the average Lerner Index across all firms is the HHI divided by the elasticity of demand. In a symmetric oligopoly, this relationship holds for each firm

$$\frac{p - mc}{p} = \frac{1}{n\varepsilon} = \frac{HHI}{\varepsilon}.$$

In an asymmetric oligopoly, the ratio $\frac{HHI}{\varepsilon}$ will equal the average of the Lerner indices of the strategic firms, weighted by their market share (see Shapiro, 1989). The use of the HHI has been subject to several criticisms, and practical implementation of competition policy often goes further to consider the implications of equilibrium oligopoly models (Farrel and Shapiro, 1990). However, the insights provided by even the simple Cournot result illustrates the relationship of competition, firm size, and market demand elasticity. Further, the importance of this relationship, as implied by the HHI, is embedded within much of competition policy.

One criticism of the focus on firm concentration is that there are many other mitigating factors to consider, such as cost-reducing synergies and the potential for learning and innovation. The relationship between horizontal and vertical structures has also been a subject of recent scrutiny (see Gans, 2006). Another potentially important element to consider that has not received as much attention in anti-trust circles is the prevalence of fixed-price forward contracting in an industry.

Starting with the work of Allaz and Vila (1988), a line of theoretical work has explored the extent to which the existence of forward markets can impact competition in oligopolistic markets. Much of this work has focused on the electricity industry, in part because it features three elements present in the Allaz and Vila model, oligopoly suppliers, homogenous commodity products, and robust forward markets.[1] Empirical research on the electricity industry also indicates the extent of forward contracting by suppliers has been an important determinant in the competitive performance of specific markets.[2] Forward obligations have generally been ignored by anti-trust authorities, but the FERC is proposing changes to its horizontal market power screens that would account for such commitments.[3] However, the new FERC method applies a very crude measure of contract cover, and is limited to consideration of pre-existing contracts. The focus on existing contracts ignores the impact that incentives to sign new contracts can have on the competitive outlook for a market.

Despite the empirical and theoretical examination of the Allaz and Vila framework, relatively little insight has been developed about the implications of their model for general oligopoly environments. This paper extends the model of Allaz and Vila, which features 2 firms and constant marginal cost, to accommodate a general number of oligopolists and increasing marginal costs. Both of these features are important characteristics of many markets subject to review by competition policy authorities. From this more representative model, one can examine how specific market characteristics may influence the contracting decision and its impact on market prices. Since the impact of contracts depends upon the parameters of the model, these impacts are presented in the context of parameter values drawn from several existing electricity markets.

The implications of the model are that the presence of a market where firms trade fixed price

[1] See Powell (1993), Newbery (1998), and Green (1999).
[2] Wolak (2000), Bushnell, Mansur, and Saravia (2004).
[3] See FERC (2004).

contracts that are publicly acknowledged can significantly reduce the impact of horizontal market power. A forward contract has the effect of publicly committing one firm to produce more, thereby inducing its rivals to react by producing less. As each firm considers the effect of a forward contract on its rivals' output, the forward market effectively increases the conjectural variation by firms. Since this is an oligopoly effect, there is no impact on a single firm market. The impact of a forward market is weakest with relatively few competitors and increases rapidly with the number of firms. In fact for the case of constant marginal cost, the impact of introducing a single round of forward trading, as measured by the Lerner index, is equivalent to squaring the number of firms in the market. In contrast to the conventional interpretation of the HHI described above, the presence of forward contracts therefore magnifies the impact of firm concentration relative to that of firm elasticity on the competitive performance of a market.

2 Contracts and the US Electricity Industry

Experiences with electricity industry liberalisation have varied greatly around the world. Differences in market design, regulatory oversight, and market structure no doubt play important roles in determining the relative performance of markets. However, much recent research points to the degree of vertical commitments between generation and retail as a key determinant of an electricity market's competitive performance. Most of the "successes" of electricity restructuring have featured markets with either a large amount of long-term supply contracts between generators and retailers or a continued integration between generation and retail, with the retailer's ability to raise prices restricted by regulators or transition arrangements.[4] By contrast, the California market was notorious for its lack of long-term arrangements between retailers and suppliers.

However, when one surveys the world's restructured electricity markets, a striking feature is the extent to which the degree of forward contracting has been driven by regulatory intervention. Regulators in many markets required that long-term vesting or "buy-back" contracts be linked

[4] Wolak (2000) finds a significant impact of contracts on the performance of the Australian market. Fabra and Toro (2005) demonstrate that a regulatory transition mechanism, which had the effect of a fixed-price contract on firms, played a key role in the Spanish market. Hortacsu and Puller (2004) include estimates of forward positions in their analysis of bidding behavior in the Texas market. These positions have an important effect on the bidding incentives of firms there.

to the divestiture of generation assets. The non-utility producers who purchased these assets were obligated to provide power to the utilities that had previously provided the generation and who remained responsible for serving retail load. In other markets, such as Texas and the mid-Atlantic region, utilities have transfered generation assets to non-utility affiliates, thereby remaining vertically integrated. These transfers have been accompanied by transition arrangements that restrain the prices that the distribution utility is allowed to charge its retail customers Although there is some dispute over whether regulators forbade the use of long-term contracts in California, the CPUC certainly did not encourage them. Thus while empirical research strongly supports the hypothesis that contracts have been critical to spot market performance, we remain relatively uninformed about the level of contracting we might expect if such decisions were left to the market, rather than dictated by regulatory policy. With transition arrangements set to expire over the next several years in many U.S. markets, this becomes an increasingly important question.

Currently in the United States, policy makers are still struggling with what the post-transition organization of the industry will look like. The provision of retail service to residential customers has not developed as a robust competitive enterprise, with the possible exception of Texas. The vast majority of residential utility customers will continue to have their electricity acquired for them by their incumbent distribution company. Regulators who had at one point imagined that restructuring would eventually bring an end to retail rate regulation have instead been forced to confront the task of setting rates for distribution companies that are large buyers on the wholesale market. In doing so, regulators have had to balance the desire to provide incentives to minimize purchase costs with a need for the utilities to recover their wholesale cost. While a fixed rate structure can provide very powerful incentives to a distribution company, if they are set significantly below wholesale costs the inevitable result is a financial crisis, as it was in California. Conversely, a blanket pass-through of costs provides no incentive for utilities to either aggressively seek low prices or hedge their cost risk.

Most restructured markets in the U.S. are now turning toward a process of organized procurement by utilities with varying degrees of oversight by local regulators. In the northeast, utilities are sub-contracting the role of Provider of Last Resort (POLR) or Basic Generation Service (BGS) to energy service firms who agree to serve utility demand at a contracted price for a period ranging from 6 months to several years.[5] In California and other regions, it appears that the utility's role will be to acquire electricity supply directly from physical producers.

The developments described above form the background to the stylized model developed in the following sections. The institutional framework is a single procurement round, either through auction or a less formal process, that is reasonably transparent because of regulatory participation. This is in contrast to the short-term trading that goes on between utilities, suppliers, and speculative trading firms that is for the most part not publicly transparent. The public commitment of a physical producer to a retail supplier can play the role of a credible commitment to raise production, thereby causing competitors without such commitments to reduce output. The procurement occurs in an oligopoly environment with a finite number of producers capable of providing supply to the distribution company. In the following section, an analytical model that can be used to analyze this institutional framework is developed. The impacts of forward contracts will depend upon the characteristics of a specific market. The model is then analyzed using paramter values estimated from data on existing U.S. markets.

3 A linear demand model with n Cournot firms

Allaz and Vila develop a nested equilibrium model of duopolists engaging in forward and spot trading. They assume that all participants are risk neutral and that suppliers engage in Cournot competition. Demand is a passive participant in the market. It is represented by an inverse demand function. The forward positions of suppliers are assumed to be public knowledge. The model also assumes that forward and spot prices are efficiently arbitraged, so that forward prices will equal the expectation of spot prices.

Previous work has analyzed the implications of different aspects of these assumptions. Hughes and Kao (1997) demonstrate the importance of the public knowledge of the forward commitment.

[5] Loxley and Salant (2004) describe the auction mechanism for procuring for Basic Generation Service in New Jersey.

A stronger conjectured response by strategic players can weaken, or even reverse the results.

Green (1999) utilizes an assumption of linear supply-function competition, rather than Cournot competition in the spot market. This approach complicates the conjectured impact of contracts signed by one player on the output of other players. At an extreme opposite of the AV model, Mahenc and Salanie (2004) find that when firms engage in differentiated Bertrand competition in the spot market, the ability to sign forward contracts can reduce competition. Ferreira (2003) examines a context in which there are infinite forward contracting rounds and demonstrates that a kind of "folk-theorem" result can arise, supporting a range of equilibria. Liski and Monterro (2006) demonstrate conditions in which repeated contracting can faciliate tacit collusion. Green and Le Coq (2006) argue that the risk of facilitating collusion is greatly reduced when the contracts are of longer term (*i.e.* cover many spot periods).

Clearly the context in which forward markets exist is important to the implications of those markets for competition. The pro-competitive effects are likely to be strongest in markets for relatively homogenous commodities, where a finite number of publicly visible transactions play a significant role. Markets for electricity, crude-oil, gasoline, metals, and perhaps some agricultural products fit this description. Any realistic examination of even these markets requires extending the basic AV model.

This section derives a variation of the AV model that incorporates a general linear demand function and an arbitrary number of symmetric firms with affine marginal costs. Market demand is modeled as $Q_t = a_t - bp_t$, or $p_t = \frac{a_t - Q_t}{b}$. For Cournot firm i, marginal cost is modeled as $c(q_i) = K + cq_i$. In the following subsections, the equilibrium conditions for the spot market output of the Cournot firms are derived. By nesting that spot market outcome within a 2 period model, one can then derive the equilibrium level of forward market contracts.

3.1 Spot market

If firms have entered into forward contracts, then spot market profits will include a term q_i^f, denoting the forward position of firm i. The spot market profit of firm i is therefore

$$\pi_i(q_i, q_{-i}, q_i^f) = \left(\frac{a - q_i - \sum_{j \neq i} q_j}{b}\right)\left(q_i - q_i^f\right) - C(q_i) = \left(\frac{a - Q}{b}\right)\left(q_i - q_i^f\right) - C(q_i)$$

where $Q = q_i + \sum_{j \neq i} q_j$, is the total output of all Cournot firms (including firm i). For a given set of demand parameters a and b, the Cournot equilibrium is characterized by setting marginal revenue equal to marginal cost. For an arbitrary level of forward contracts, the equilibrium is described by the following first order condition for maximizing the profit function described above.

$$\frac{\partial \pi_i(q_i, q_{-i}, q_i^f)}{\partial q_i} = \frac{a - \left(q_i - q_i^f\right) - Q}{b} - K - cq_i = 0 \tag{1}$$

The optimal quantity, q_i, in this context is therefore

$$q_i^* = \frac{a + q_i^f - \sum_{j \neq i} q_j - Kb}{2 + bc} \tag{2}$$

From this framework, the first result of the model can be stated.

Lemma 1 *Assume a market of symmetric Cournot producers with costs and demand as described above. For firm i, with contract level q_i^f,the optimal production quantity, as a function of every firm's contract position, is*

$$q_i(q_i^f, q_{-i}^f) = \frac{(a - bK) + \left(\frac{(n+bc)q_i^f - \sum_{l \neq i} q_l^f}{(1+bc)}\right)}{(n + 1 + bc)}. \tag{3}$$

Proof. *See Appendix.* ■

Aggregate market production is therefore

$$Q = \sum q_i = \frac{n\,(a - bK) + \sum_j q_j^f}{(n + 1 + bc)}. \tag{4}$$

If symmetry is extended to the forward market, with all $q_i^f = q^f$, total market quantity and prices are therefore

$$Q = \frac{n\left(a + q^f - bk\right)}{(n + 1 + bc)}, \quad p = \frac{a(1 + bc) + nbk - nq^f}{b(n + 1 + bc)}$$

3.2 The Contract Market

The equilibrium for the forward market can be calculated by nesting the equilibrium conditions from the spot market within the profit maximization problem for the forward market. Following Allaz and Vila, I assume that there are no arbitrage opportunities. In other words, the forward price, p_f, is assumed to equal the spot price, p_s. Profits therefore take the form

$$\pi_i(q_i, q_{-i}, q_i^f) = p_f q_i^f + p_s(Q)\left(q_i - q_i^f\right) - C(q_i) = p(Q(q_i^f, q_{-i}^f))q_i - C(q_i)$$

where the latter equality is the result of the no arbitrage assumption, $p_f = p_s$. Note that the term $Q(q_i^f, q_{-i}^f)$ is notation for

$\sum_j q_j(q_i^f, q_{-i}^f)$. The first order condition for maximizing the profit of firm i in the forward market with respect to contract level q^f is

$$\frac{\partial \pi_i\left(q_i^f, q_{-i}^f\right)}{\partial q_i^f} = p\left(Q\right)\frac{\partial q_i}{\partial q_i^f} + p'(Q)q_i\sum_j \frac{\partial q_j}{\partial q_i^f} - C'(q_i)\frac{\partial q_i}{\partial q_i^f}. \tag{5}$$

Using the marginal impact of quantity commitment that can be derived by differentiating (3) with respect to q_i^f, the above conditon can be expressed as

$$\begin{aligned}\frac{\partial \pi_i\left(q_i^f, q_{-i}^f\right)}{\partial q_i^f} &= p\left(Q\right)\frac{(n+bc)}{(n+1+bc)\left(1+bc\right)} + p'(Q)q_i\frac{1}{(n+1+bc)} \\ &\quad -C'(q_i)\frac{(n+bc)}{(n+1+bc)\left(1+bc\right)}.\end{aligned} \tag{6}$$

Note that the second term in the marginal revenue equation differs from the standard Cournot best response because the term $\frac{\partial Q}{\partial q_i^f}$ is not the same as the term $\frac{\partial q_i}{\partial q_i^f}$. In other words, the choice of contract level by firm i affects the spot market production of all other firms. Firm i is making a public and credible commitment to produce more by taking on contract level q_i^f, thereby leading to a reduction in spot production by other firms. This implies that a confidential agreement, although it would impact a firm's own spot production, would not have an impact on the production of other firms. Given this fact, risk neutral producers would prefer not to enter into confidential contracts (see Hughes and Kao, 1997). From the above first order conditions, one can derive a second result.

Proposition 1 *For a symmetric market as described above, the equilibrium level of contracting by an individual Cournot firm in a single forward market will be*

$$q^f = \frac{(a-bk)(n-1)}{(n+bc)^2 + (1+bc)} \tag{7}$$

Proof. Note that profit as defined by equation (6) is strickly concave in q_i^f. By substituting q_i and $Q = \sum_j q_j$ from (3) and (4) into (6), the first order condition for the optimal contract quantity of firm i is

$$\begin{aligned}
\frac{\partial \pi_i \left(q_i^f, q_{-i}^f\right)}{\partial q_i^f} &= \frac{a(1+bc) + nbk - \sum_j q_j^f}{b(n+1+bc)^2} \frac{(n+bc)}{(1+bc)} \\
&\quad - \frac{\left(a - bk + \frac{(n+bc)q_i^f - \sum_{j\neq i} q_j^f}{(1+bc)}\right)}{b\left(n+1+bc\right)^2} \\
&\quad - \frac{bk\left(n+1+bc\right)}{b\left(n+1+bc\right)^2}\frac{(n+bc)}{(1+bc)} \\
&\quad - bc\frac{\left(a - bk + \frac{(n+bc)q_i^f - \sum_{j\neq i} q_j^f}{(1+bc)}\right)}{b\left(n+1+bc\right)^2}\frac{(n+bc)}{(1+bc)}
\end{aligned}$$

From symmetry, with all $q_i^f = q^f$ this reduces to

$$\begin{aligned}
\frac{\partial \pi_i \left(q_i^f, q_{-i}^f\right)}{\partial q_i^f} &= \frac{a(1+bc) + nbk - nq^f}{b(n+1+bc)^2} \frac{(n+bc)}{(1+bc)} - \frac{\left(a - bk + q^f\right)}{b\left(n+1+bc\right)^2} \\
&\quad - \frac{bk\left(n+1+bc\right)}{b\left(n+1+bc\right)^2}\frac{(n+bc)}{(1+bc)} \\
&\quad - bc\frac{\left(a - bk + q^f\right)}{b\left(n+1+bc\right)^2}\frac{(n+bc)}{(1+bc)}
\end{aligned}$$

By collecting terms, this reduces to

$$q^f\left[(n+bc)^2 + 1 + bc\right] = [a-bk]\left(n+bc\right) - (a-bk)\left(1+bc\right)$$

or

$$q^f = \frac{(a-bk)(n-1)}{(n+bc)^2 + (1+bc)}$$

■

Combining conditions (3) and (7) we have the following equilibrium spot quantities and prices.

$$Q = \frac{n\left[n+bc\right](a-bk)}{\left[(n+bc)^2 + 1 + bc\right]}, p = \frac{a + a\left[n+1+bc\right]bc + n\left[n+bc\right]bk}{b\left[(n+bc)^2 + 1 + bc\right]} \tag{8}$$

3.3 Comparitive Statics

Given the above derivation, the ratio of production by Cournot suppliers that is sold forward is

$$\frac{q_f}{q} = \frac{(n-1)}{(n+bc)}.$$

This value rapidly increases in n between 2 and 8 suppliers and levels off in the range of 80-90% of the volume being contracted.

By comparing the equilibrium quantities implied by (8) to those that would result if there were no contracting, we can derive the differential impact of the addition of a forward contracting round.

Corollary 1 *The percent increase in output due to the existence of a single forward market is equal to*

$$\frac{\Delta Q}{Q} = \frac{n-1}{\left[(n+bc)^2 + 1 + bc\right]}$$

Note that while the percent change in output is sensitive to the slope of the demand function, the effect is independent of the demand function intercept. Figure 1 graphs level sets of the above relationship. The impact on production quantity is uniformly decreasing in demand slope. For a very small number of firms (less than four) the quantity impact is increasing in n. For example, with a demand slope value of 40 ($/MWh), increasing the number of firms from 2 to 3 raises the percent increase in output from contracting from less than 12% to close to over 13.5%. For more than about four firms the impact becomes decreasing in n.

Corollary 2 *The change in the lerner index due to the existence of a forward market is equal to*

$$\Delta \frac{p - MC}{p} = \frac{a - bk}{a(1+bc) + nbk} - \frac{(a-bk)(1+bc)}{a + a\left[n+1+bc\right]bc + n\left[n+bc\right]bk}. \qquad (9)$$

Proof. The price-cost margin, $p - MC$, with and without contracts is

$$\frac{a(1+bc) + nbk}{b(n+1+bc)} - k - c\frac{(a-bk)}{(n+1+bc)}$$

and

$$\frac{a + a\left[n + 1 + bc\right]bc + n\left[n + bc\right]bk}{b\left[(n + bc)^2 + 1 + bc\right]} - k - c\frac{\left[n + bc\right](a - bk)}{\left[(n + bc)^2 + 1 + bc\right]}$$

respectively. When each term is divided by its respective equilibrium price and simplified, the result is the first and second terms on the lefthand side of (9). ■

The pro-competitive impact of forward contracting therefore depends upon the same factors that influence the competitiveness of the market absent a forward market. A natural question to examine is the extent to which the model predicts contracts offset an increase in market concentration. This is easiest to examine under an assumption of constant marginal cost ($c = 0$).

Corollary 3 *Assume constant marginal costs and the assumptions applied to previous results. The impact of one round of forward contracting on the Lerner index is equivalent to an increase in firms to a number equal to the square of the number of firms in the market.*

Proof. From the first term on the right hand side of equation (9), when $c = 0$ the Lerner index without contracts is equal to $\frac{a-bk}{a+nbk}$. The second term in equation (9) gives the Lerner index with contracts, which equals $\frac{(a-bk)}{a+nnbk}$ when $c = 0$. ■

Note that in the standard model the Lerner index is equal to $\frac{-1}{n\varepsilon}$. In the model with contracting, the elasticity at the equilibrium price is $-\frac{a+n^2bk}{n^2(a-bk)}$. The Lerner index in this case is therefore equal to $\frac{-1}{n^2\varepsilon}$. When $c > 0$, the interaction of the number of firms, contracting and the Lerner index becomes more complex. Increasing marginal costs tend to reduce the impact of contracts on the Lerner index. To make a valid comparison, we need to define firm specific marginal cost c in terms of a fractional share of total industry marginal cost, such that $c = nz$, where $k + zq$ represents the aggregate marginal cost function for the entire industry. With this representation, we can examine the impact of additional firms while holding the aggregate costs of production for the industry constant. Figures 2a and 2b illustrate the impact of adding a round of contracts as a function of the number of firms and the slope of marginal cost for a representative set of parameters drawn from the examples in subsequent sections, where Figure 2a assumes a demand slope of 25 and Figure 2b assumes a slope of 125. The impact of contracts declines with the slope of marginal costs, z, and how the marginal impact of an additional firm also declines sharply as the slope of marginal cost increases. This is in part because at higher marginal costs, overall mark-ups are lower even in the absence of contracts. The scope for contracts to reduce margins is therefore lessened with steeper marginal cost.

4 Empirical Model

Given the results of the theory model in Section 3 it is natural to ask what kind of pro-competitive impact a single contracting round would have on actual electricity markets. The theory model developed above can be used to address this question. Using detailed data from several markets, the supply and demand characteristics can be distilled to match the framework of the theory model. The results of the theory model for the range of parameter values taken from these markets are then demonstrated.

The first step is to calculate a term for the equivalent number of firms in a market. Table 1 summarizes the actual market structure in the three markets for 1999. Since firms are not symmetric, a comparable number of symmetric firms is generated by calculating a Hirschman-Herfindahl concentration statistic for the major thermal suppliers in a market and then mapped to the equivalent number of symmetric firms that would generate the same HHI value. For example, PJM which featured 9 large firms of varying capacity in 1999, had a concentration (measured by HHI) equivalent to that of about 7 equal sized firms. Note that the measures of firm size in Table 1 focus only on thermal generation. Unlike Bushnell, Mansur, and Saravia (BMS, 2005), hydro generation is here assumed to operate competitively and does not effect the output decisions of strategic firms.

Supply costs are taken from aggregating the thermal generation within the control area to form a single supply function. Actual supply costs are simplified to fit the affine function of the theory model. Thermal generation costs are taken from previous empirical work studying these markets.[6]

[6] Thermal generation costs are taken from previous empirical work studying these markets. For each market, previous work has estimated the market-wide marginal cost of serving demand for all observed demand levels. For more details see Borenstein, Bushnell, and Wolak (2002), Mansur (2003), and Bushnell, Mansur and Saravia (2005).

As in BMS, unit-level generation costs are averaged over one month. A linear regression of marginal cost on production quantity yields the values for the intercept k and slope c of the marginal cost function.[7] This aggregate marginal cost function is then subdivided into n affine supply functions according to the number of equivalent firms in a market.

Estimating Residual Demand

Demand is estimated from historic market data. The method similar to that used in BMS, but focuses on the linear functional form. Since end-use demand in U.S. wholesale electricity markets is effectively inelastic to hourly prices, the slope b of the model represents the *residual* demand faced by Cournot firms. This residual demand function is modeled as market demand minus the slope of the supply of net imports (imports minus exports) into the market and the production of other small, fringe plants located within the market.[8] For all markets, the sample period is the summer (June to September). Both 1999 and 2000 are estimated for New England and California, while data from Mansur (2004) covers only 1999 in PJM.

For each hour t, the production from fringe supply is estimated using daily temperature in bordering states ($Temp_{st}$),[9] and fixed effects for hour h of the day ($Hour_{ht}$) and day j of week (Day_{jt}). For each market and year, fringe supply (q_t^{fringe}) is estimated as a function of the actual market price p_t, proxies for cost shocks (fixed effects for month i of the summer ($Month_{it}$)), proxies

[7] The intercept of this regression, which represents the value of k, is constrained to be non-negative. Since the affine cost function required by the analytical model is a crude fit for electricity supply costs, a market with a substantial amount of nuclear capacity such as PJM can produce a negative intercept when costs are extrapolated out of sample to very low levels of production.

[8] In California and New England, this supply includes net imports and must-take plants (see Borenstein, Bushnell, and Wolak, 2002, and Bushnell and Saravia, 2002). In California, these plants include nuclear and independent power producers. Nuclear power plants are owned by strategic producers in the other 2 markets are not included in the fringe in those markets.The estimates include only net import supply in PJM as small independent generation sources are negligable in that region.

[9] For California, this includes Arizona, Oregon, and Nevada. New York is the only state bordering New England, while in PJM, bordering states include New York, Ohio, Virginia, and West Virginia. The temperature variables for bordering states are modeled as quadratic functions for cooling degree days (daily mean below 65° F) and heating degree days (daily mean above 65° F). As such $Temp_{st}$ has four variables for each bordering state. These data are state averages from the NOAA web site daily temperature data.

for neighboring prices ($Temp_{st}, Day_{jt}, Hour_{ht}$), and an idiosyncratic shock (ε_t):

$$q_t^{fringe} = \sum_{i=6}^{9} \alpha_i Month_{it} + \beta p_t + \sum_{s=1}^{S} \gamma_s Temp_{st} + \sum_{j=2}^{7} \delta_j Day_{jt} + \sum_{h=2}^{24} \phi_h Hour_{ht} + \varepsilon_t. \quad (10)$$

As price is endogenous, (10) is estimated using two stage least squares (2SLS). The instrument for price is the natural log of hourly quantity demanded inside each respective ISO system. Typically, quantity demanded is considered endogenous to price: however, since the derived demand for wholesale electricity is completely inelastic, this unusual instrument choice is valid in this case.[10] Demand is excluded from the second stage as it only indirectly affects net imports through prices.

The coefficient estimates for the linear specification, shown in (10), are then used to determine the N strategic firms' residual demand (Q_t). In equilibrium, $Q_t = \sum_{i=1}^{N} q_{i,t}$ so a_t, the vertical intercept of the demand function, is defined as:

$$a_t = \sum_{i=1}^{N} q_{i,t}^{actual} + \beta p_t^{actual}, \quad (11)$$

where p_t^{actual} and $q_{i,t}^{actual}$ are the actual price and quantities produced in any given hour. Therefore, for each hour, the inverse residual demand is:

$$p_t = \frac{a_t - \sum_{i=1}^{N} q_{i,t}}{\beta}. \quad (12)$$

Since data on specific firm level production are not available for all markets, the aggregate production of Cournot firms, $\sum_{i=1}^{N} q_{i,t}$, is derived by subtracting the production from imports, hydro, and fringe sources from the aggregate market demand. The residual is the quantity supplied by Cournot producers.

4.1 Results

Table 2 describes the relevant market parameters for the 3 markets studied. The cost values highlight the differences in the supply portfolios across these markets. The PJM market features

[10] The majority of customers in these markets faced fixed rates based upon transition levels set by regulators. Many unregulated retailers based their rates upon these default levels. Those customers whose rates did change in response to wholesale prices had their rates adjusted only periodically, such as monthly. The number of customers on 'real-time' rates in these markets was negliable. Thus there were almost no end-users who at time t paid a retail price based upon the wholesale price at time t.

substantially more nuclear and coal plants than the other two markets. The dominance of these low marginal cost baseload technologies is reflected in the zero intercept and relatively modest slope of the linear estimate of the PJM supply function. By contrast, the New England and California markets are much more dependent upon generation fueled by natural gas and fuel oil. The increase in natural gas prices between 1999 and 2000 has a dramatic impact on the supply functions in both these markets. Both the intercept and slope terms increase substantially from 1999 to 2000.

The second column in Table 2 presents the results of the residual demand elasticity regressions, as expressed by the parameter β, the slope of residual demand function, from equation (12).[11] This parameter is used as the demand slope b from equation (8) to calculate the market results. Recall that these values reflect the elasticity of supply from fringe production such as imports and independent power generation. California experienced a dramatic reduction in both the level and elasticity of imports from 1999 to 2000. This is reflected in the nearly 5 fold reduction in the residual demand slope. The combination of higher supply costs and reduced import elasticity were, along with the lack of forward contracts, major contributors to the crisis of 2000-01 in California. By contrast, the New England market experienced a significant increase in import elasticity from 1999 to 2000, in part due to better integration with the neighboring New York market. The PJM market, which is more than twice the size of New England, imports very little power and has very few small fringe producers. PJM had the smallest residual demand elasticity of the markets studied.

The market parameters described in Table 2 are applied to hourly price and quantity data for the months of June 1999 in PJM, California and New England, as well as June 2000 in California and New England. Table 3 presents the implications of the model for contracting and competition. The second column lists estimates of the contracting levels based upon the long-term retail commitments made by firms in each market. The third column describes the contracting level predicted by the model for the peak (highest demand) hour of the month that is modeled. The contracting levels predicted by the model are relatively similar to those actually in place in 1999, with the important exception of California. Recall that there were essentially no public long-term commitments in

[11] For 1999, these values are the same as reported in Bushnell, Mansur, and Saravia (2005).

the California market.

The fourth and fifth columns of Table 3 describe the average Cournot price predicted by the model with no contracts, and with one round of contracts, respectively. The level of contracts used to derive prices in column five is based upon the model of endogenous contracts given by equation. The last column lists the actual average price in each market. In all markets, the addition of contracting has a substantial impact on equilibrium prices. The impact is greatest in relatively low elasticity environments with a more modest concentration of supply. This best describes the PJM market, which has the residual demand elasticity and lowest concentration of the markets. Table 4 also provides the actual average price for each of the markets studied. This relatively crude Cournot model does a decent job of replicating California prices, but yields prices quite a bit higher than actual levels in both PJM and New England. One contributor to this disparity is the adjustment made to account for firm assymetry. Taking an equivalent number of firms based upon HHI undervalues the effect of increasing the number of firms. For example, when contracting is considered, 6 assymetric firms will produce more competitive outcomes than 4 symmetric ones, even if the implied HHI from both markets is the same. If the actual number of firms, rather than a concentration adjusted equivalent, is used, average June 1999 prices in New England and PJM fall to 41 \$/MWh and 63 \$/MWh, respectively.

4.2 Relative value of contracting vs. demand elasticity

The above theoretical results, as well as the empirical literature on electricity markets indicate that markets with the best competitive performance are those where the large retailers, who are the buyers on the wholesale market, pursued vertical arrangements with suppliers. At the same time, both theoretical work and empirical simulations support the argument that increasing the elasticity of end-use demand through a wide-spread implementation of the real-time pricing of electricity to end users would have had substantial pro-competitive effects, in addition to providing other benefits.[12]

[12] See Borenstein (2000) for a discussion of these issues. Oligopoly simulations in Borenstein and Bushnell (1999) as well as Bushnell (2004) show that the California market would have been much more competitive with even a modest adoption of real-time pricing by end-users.

These two effects would, at first glance, appear to be at odds with each-other. On the one hand, there are pro-competitive benefits from retailers entering into long-term vertical arrangements with suppliers. Yet in the absence of retail competition, the strongest motivation a retailer could have for entering into such arrangements would be regulatory restraints on the ability of that retailer to adjust customer tariffs in response to wholesale price shocks. If retailers are simply allowed to completely pass on wholesale price shocks, as they would in a pure real-time pricing environment, their incentive to hedge wholesale price risk is greatly reduced if not eliminated. Of course end-use customers would now have a stronger incentive to hedge wholesale price risk, but this group constitutes a much more disparate collection of small consumers many of whom spend relatively small amounts of their individual budgets on electricity.

Borenstein (2005) outlines the solution to this seeming paradox. A utility retailer would offer a real-time pricing tariff bundled with a fixed-quanitity hedge that would preserve end-users' marginal incentive to adjust to wholesale prices. The utility has therefore still committed to provide large amounts of energy at fixed prices, while end-users still face the wholesale price as the marginal opportunity cost of deviations from the quantity they have hedged. Despite the strong merits of such a system, its adoption in practice has been extremely limited. It is therefore still interesting to explore the relative pro-competitive benefits of increasing demand elasticity and introducing a single round of long-term contracting by utilities.

This question can be approached by calculating for each market the alternative demand slope, $\widehat{b}$, that would equilibrate a no-contract Cournot price in each market with the price resulting from one round of contracting (using the estimated slope b). By rotating the demand curve around the 'with-contracts' equilibrium price-quantity point a new demand curve with slope $\widehat{b}$ and horizontal intercept $\widehat{a}$ can be produced. In other words, for a peak demand hour, define the equivalent slope $\widehat{b}$ such that

$$\frac{\widehat{a}(1+\widehat{b}c)+n\widehat{b}k}{\widehat{b}(n+1+\widehat{b}c)}=\frac{a+a\left[n+1+bc\right]bc+n\left[n+bc\right]bk}{b\left[(n+bc)^{2}+1+bc\right]}$$

where the left term is the equilibrium price without contracts and the right term is the price with one round of contracts. The new intercept, $\widehat{a}$, is equal to $Q_c + P_c * \widehat{b}$, where Q_c and P_c are the 'with-contracts' Cournot equilibrium quantity and price, respectively. The results are presented in table 4. The first column presents the actual residual demand slope from the empirical estimation described above. The second column describes the equivalent slope that would produce the same Cournot equilibrium price in the absence of forward contracting. The last two columns calculate the elasticities implied by those slopes evaluated at the Cournot equilibrium price-quantity point. In every market, the value of a round of contracting is equivalent to a massive increase in demand elasticity. Adding contracting is equivalent to more than doubling the elasticity in California and a more than 5 fold increase in PJM.

5 Conclusion

Traditionally, competition policy has operated with a focus on market structure, particularly the horizontal organization of supply. It has long been recognized that other factors may be important in mitigating, or amplifying the market power implied by a given horizontal concentration. Many of these factors, such as vertical relationships, have been given serious weight in the application of competition policy in practice. The competitive implications of the ability of firms to trade in transparent forward markets has received considerable attention in the academic literature. Their implications have not had much impact on policy however.

In this paper, I examine the implications of forward contracts on oligopoly environments by extending the model of Allaz and Vila to an environment with more than two firms and increasing marginal cost. The number of firms is an important factor in determining the interaction of forward markets and competition. In the case of constant marginal cost, the competitive impact of firm concentration is far greater with the existence of a single forward market relative to a single spot market. While the interaction of increasing marginal cost and firm size is complex in this model, it appears that increasing marginal cost reduces the impact of firm size on contracting for a range of parameter values drawn from existing electricity markets, but the

impact is still substantial. For those parameter values, the model indicates that the addition of one round of forward contracting is equivalent to a major increase in demand elasticity in terms of its effect on mitigating the market power of Cournot producers. These results imply that in markets where fixed price forward trading is common, the importance of firm size is greatly magnified relative to other factors. Relatively small reductions in firm concentration can yield large benefits in the context of fixed-price forward contracting.

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Appendix: Proof of Lemma 1

To demonstrate that the production level given in equation (3) constitutes an equilibrium, first consider any firm i. Note that profit for firm i is strickly concave and differentiable in q_i. Since the boundry conditions for an interior solution are satisifed, the equilibrium is described by the first order conditions of the Cournot firms. Recall that the optimal production quantity for firm i is given by

$$q_i = \frac{a - \sum_{j \neq i} q_j + q_i^f - bK}{2 + bc}.$$

By substituting (3) for q_j into the above first order condition, we have

$$q_i = \frac{a - \sum_{j \neq i} \frac{(a-bk) + \left(\frac{(n+bc) q_j^f - \sum_{l \neq j} q_l^f}{(1+bc)} \right)}{(n+1+bc)} + q_i^f - bK}{2 + bc}.$$

This reduces to

$$q_i = \frac{\left(a - bK + q_i^f\right)}{(2+bc)} - \frac{\sum_{j \neq i} \left[(a - bk)(1 + bc) + (n + bc) q_j^f - \sum_{l \neq j} q_l^f \right]}{(2 + bc)(n + 1 + bc)(1 + bc)}.$$

$$\begin{aligned} q_i &= \frac{(a - bK)}{(2 + bc)} - \frac{(n-1)(a - bK)}{(2+bc)(n+1+bc)} + \frac{q_i^f (n+1+bc)(1+bc)}{(2+bc)(n+1+bc)(1+bc)} \\ &\quad + \frac{-\sum_{j \neq i} (n + bc) q_j^f + \sum_{j \neq i} \sum_{l \neq j} q_j^f}{(2+bc)(n+1+bc)(1+bc)}. \end{aligned}$$

By separating $\sum_{j \neq i} \sum_{l \neq j} q_j^f$ into $(n-1) q_i^f + \sum_{j \neq i} \sum_{l \neq j,i} q_j^f$ we can rewrite the above as

$$\begin{aligned} q_i &= \frac{(a - bK)(2+bc)(1+bc)}{(2+bc)(n+1+bc)(1+bc)} + \frac{q_i^f (n+1+bc)(1+bc) + (n-1) q_i^f}{(2+bc)(n+1+bc)(1+bc)} \\ &\quad + \frac{-\sum_{j \neq i} (n+bc) q_j^f + \sum_{j \neq i} \sum_{l \neq j,i} q_j^f}{(2+bc)(n+1+bc)(1+bc)}. \end{aligned}$$

collecting terms and using the fact that $\sum_{j \neq i} \sum_{l \neq j,i} q_j^f = (n-2) \sum_{j \neq i} q_j^f$ we have

$$\begin{aligned} q_i &= \frac{(a - bK)(2+bc)(1+bc)}{(2+bc)(n+1+bc)(1+bc)} + \frac{q_i^f (n+bc)(2+bc)}{(2+bc)(n+1+bc)(1+bc)} \\ &\quad + \frac{-(2+bc) \sum_{j \neq i} q_j^f}{(n+1+bc)(1+bc)(2+bc)}. \end{aligned}$$

which reduces to

$$q_i = \frac{(a - bK)(1+bc) + q_i^f (n+bc) - \sum_{j \neq i} q_j^f}{(n+1+bc)(1+bc)} = \frac{(a - bK) + \frac{q_i^f (n+bc) - \sum_{j \neq i} q_j^f}{(1+bc)}}{(n+1+bc)}.$$

Table 1: Thermal Generation Capacities and Firm Size

Firm	Thermal Capacity (MW)	Share	HHI
California			
AES/Williams	3,921	0.23	0.053
Reliant	3,698	0.22	0.048
Mirant	3,130	0.18	0.034
Duke	3,343	0.20	0.039
Dynegy/NRG	2,871	0.17	0.029
total	16,963	1.00	0.2025
June 1999 Peak Demand (MW)	41,366		
Avg. Hydro, Imports & Other (MW)	20,780		
Equivalent Symmetric Firms = 4.94			

Firm	Thermal Capacity (MW)	Share	HHI
New England			
Northeast Util.	5,366	0.41	0.168
PG&E N.E.G.	2,736	0.21	0.044
Mirant	1,219	0.09	0.009
Sithe	1,810	0.14	0.019
FP&L Energy	965	0.07	0.005
Wisvest	979	0.07	0.006
total	13,075	1.00	0.251
June 1999 Peak Demand (MW)	14,568		
Avg. Hydro, Imports & Other (MW)	6,629		
Equivalent Symmetric Firms = 3.98			

Firm	Thermal Capacity (MW)	Share	HHI
PJM			
GPU Inc.	8,991	0.167	0.028
PECO Energy	8,216	0.152	0.023
PP&L Inc.	8,405	0.156	0.024
PEPCO	6,507	0.121	0.015
PSE&G	10,269	0.190	0.036
BG&E	5,773	0.107	0.011
DP&L	2,458	0.05	0.002
ACE	1,309	0.02	0.001
SCE Mission	2,012	0.04	0.001
total	53,940	1.00	0.1416
June 1999 Peak Demand (MW)	48,447		
Avg. Hydro, Imports & Other (MW)	1,285		
Equivalent Symmetric Firms = 7.06			

Table 2: Market Parameters

Market	n	b	k	c
California				
1999	4.94	125	15.63	.0017
2000	4.94	28	28.53	.0030
New England				
1999	3.94	15	9.26	.0027
2000	7.42	37	18.13	.0042
PJM				
1999	6.45	8.5	0.00	.0009

Table 3: Model Results

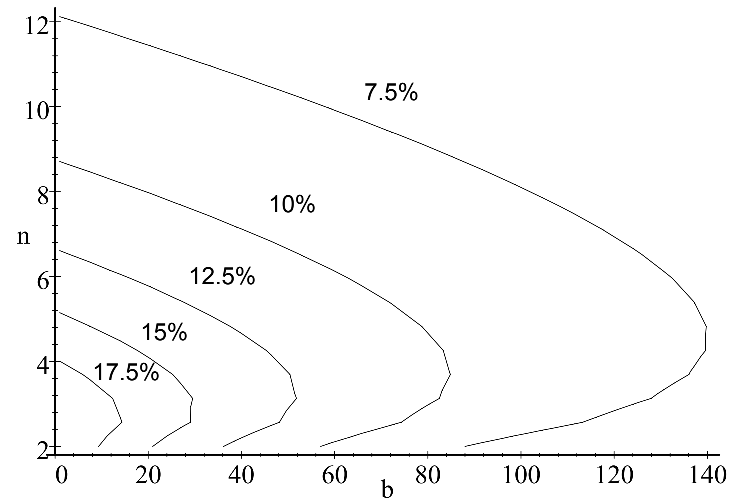
Market	Actual Contract %	Predicted Contract %	No Contracts Avg. Price	w/ Contracts Avg. Price	Actual Avg. Price
California					
June 1999	0	46	27.20	24.30	23.50
June 2000	0	62	117.03	76.58	120.20
New England					
June 1999	50	66	153.8	67.81	49.18
June 2000	40	62	85.99	63.77	38.80
PJM					
June 1999	85	83	406.40	87.10	37.10

Table 4: Equivalent Implied Elasticities

Market	Actual Slope	Equivalent Slope	Actual Elasticity	Equivalent Elasticity
California				
1999	125	182	-0.43	-.79
2000	28	61.45	-0.18	-0.52
New England				
1999	10.8	29.9	-0.11	-0.36
2000	32	59.75	-0.22	-.052
PJM				
1999	8.5	58.99	-0.02	-0.16

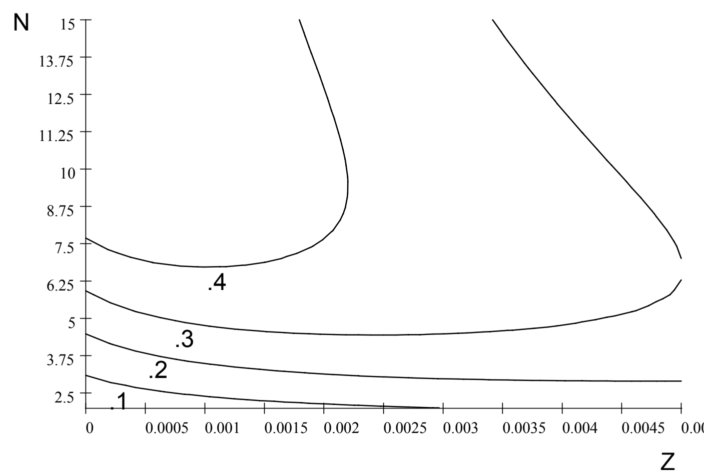
Notes: Table presents alternative values of demand slope, $\hat{b}$
which equilibrate a no-contract Cournot price from each market with the price produced from 1 round of contracting using the original demand slope, b from each market. The alternative slope is applied to a demand curve that passes through the "with contracts" equilibrium price and quantity. Elasticity is calculated at the Cournot equilibrium prices and for the peak demand hour in each market in the month of June 1999 or 2000.

Figure 1: Percent change in Cournot quantity from 1 contracting round



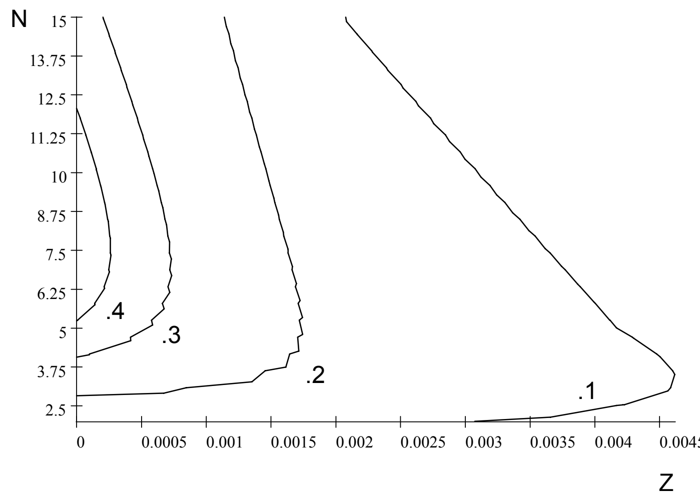
notes: marginal cost of each firm is equal to k+c, where c is assumed to be .015 for this example.

Figure 2a: Decrease in Lerner Index from 1 contracting round – increasing MC



notes: marginal cost of each firm is equal to k+n*z, where k is assumed to be 20. Demand is defined by the function a – b*p, where a is set equal to 25,000 and b equal to 25 for this example.

Figure 2b: Decrease in Lerner Index from 1 contracting round – increasing MC



notes: marginal cost of each firm is equal to k+n*z, where k is assumed to be 20. Demand is defined by the function a – b*p, where a is set equal to 25,000 and b equal to 125 for this example.

Figure 3: Calculation of Equivalent Elasticity