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Author
Wolak, Frank

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Frank Wolak

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University of California Energy Institute

2510 Channing Way, Suite 5
Berkeley, California 94720-5180
www.ucei.org

Measuring Unilateral Market Power in Wholesale Electricity Markets:

The California Market 1998 to 2000

by

Frank A. Wolak*
Department of Economics
Stanford University
Stanford, CA 94305-6072
wolak@zia.stanford.edu

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Abstract

This paper measures the unilateral incentive each of the five largest electricity suppliers in the California had to exercise market power in the state's wholesale market during the five month period June 1 to September 30 of 1998, 1999 and 2000. Using the actual bids submitted to the California Independent System Operator's (CAISO) real-time energy market, I compute the hourly price elasticity of the *ex post* residual demand curve faced by each supplier evaluated at the market-clearing price for that hour. The inverse of this hourly *ex post* residual demand elasticity quantifies the extent to which that supplier is able to raise the hourly real-time energy price above its marginal cost of supplying the last megawatt-hour (MWh) it sells in the CAISO's real-time energy market. I use the average hourly value of the inverse of the firm-level residual demand elasticity over the four month sample period of each year as a summary measure of the extent of unilateral market power possessed by each supplier. For each firm, this measure of unilateral market power is significantly higher in 2000 relative to the corresponding firm-level values in 1998 and 1999. For each of the five firms, this measure is slightly higher in 1998 than 1999. The firm-level results presented below are consistent with the view that the enormous increase in the amount market power exercised in the California market beginning in June of 2000 documented in Borenstein, Bushnell and Wolak (2002) was due to a substantial increase in the amount of unilateral market power possessed each of the five large suppliers in California.

I. Introduction

This paper measures the unilateral incentive each of the five largest electricity suppliers in the California had to exercise market power in the state's wholesale market during the five month period June 1 to September 30 of 1998, 1999 and 2000. Using the actual bids submitted to the California Independent System Operator's (CAISO) real-time energy market, I compute the hourly price elasticity of the *ex post* residual demand curve faced by each supplier evaluated at the market-clearing price for that hour. The inverse of this hourly *ex post* residual demand elasticity quantifies the extent to which that supplier is able to raise the hourly real-time energy price above its marginal cost of supplying the last megawatt-hour (MWh) it sells in the CAISO's real-time energy market. I use the average hourly value of the inverse of the firm-level residual demand elasticity over the period June 1 to September 30 of each year as a summary measure of the extent of unilateral market power possessed by each supplier.

For each firm, this measure of unilateral market power is significantly higher in 2000 relative to the corresponding firm-level values in 1998 and 1999. For each of the five firms, this measure is slightly higher in 1998 than 1999. Severin Borenstein, James Bushnell, and Frank Wolak (2002), hereafter BBW report quantitatively similar results across these three years for their market-level measures of the amount market power exercised in the California market. The average value of their market-level measure was significantly higher during 2000 than in either 1998 or 1999, and the average value in 1998 was slightly higher than the average value in 1999.

The firm-level results presented below are consistent with the view that the enormous increase in the amount market power exercised in the California market beginning in June of 2000 documented in BBW was due to a substantial increase in the amount of unilateral market power possessed each of the five large suppliers in California. The many investigations of the causes of the California Electricity Crisis currently underway have not uncovered evidence that suggests suppliers coordinated their actions to raise prices in the California. The firm-level measures of market power presented below indicate that coordinated actions by suppliers were unnecessary to bring about the substantial price increases that occurred during the period June 1, 2000 to September 30, 2000. My results are consistent with these price increases in the CAISO's real-time market being the result of the expected profit-maximizing response of each of the five suppliers to the bidding behavior of all other market participants in the California market.

The next section outlines the theoretical justification for measuring firm-level market power in bid-based electricity markets. The third section describes how it is implemented for the CAISO's real-time market. The fourth section presents my empirical results. The final section concludes and discusses directions for future research.

II. Measuring Firm-Level Market Power

Understanding how suppliers formulate their expected profit-maximizing bidding strategy is a necessary first step to measure firm-level market power in a bid-based electricity market. Wolak (2000) presents a model of expected profit-maximizing bidding behavior in a wholesale electricity market. That paper demonstrates that computing a firm's expected profit-maximizing bidding strategy, under certain conditions, reduces to finding the set of ex post profit-maximizing price and quantity pairs for all possible residual demand realizations that the firm might face. Figure 1 presents an example of this procedure for the case of two possible residual demand realizations facing Firm A, a participant in a bid-based wholesale electricity market.

Let MC(q) equal the marginal cost of output level q. Let $DR_i(p)$ equal the residual demand realization, for state of the world i, for i = 1 or 2. The residual demand facing Firm A is equal to the market demand for that hour for state of the world i, Q_i^d, less the aggregate supply bid curve of all other market participants for that hour, $SO_i(p)$, for state of the world i. The function $SO_i(p)$ gives the total amount of energy all other market participants besides Firm A are willing to supply to the market during that hour at price, p, under state of the world i. Mathematically, $DR_i(p) = Q_i^d - SO_i(p)$. Because the market is simultaneous auction, at the time Firm A submits its willingness to supply bid, it does not know which of these two residual demand curve realizations will occur.

A firm with the marginal cost curve given in Figure 1 would formulate its expected profit-maximizing bid curve, S(p), as follows. It would compute the profit-maximizing price and quantity pair associated with each realization of the residual demand curve. If residual demand realization $DR_1(p)$ occurs, the firm would like to produce at the output level q_1 where the marginal revenue curve associated with $DR_1(p)$ crosses MC(q), the Firm A's marginal cost curve. The market price at this level of output by Firm A is equal to p_1. The profit-maximizing price and quantity pair associated with residual demand realization $DR_2(p)$ is equal to (p_2,q_2). If Firm A faced these two possible residual demand realizations, its expected profit-maximizing bidding strategy would be any function passing through the two profit-maximizing price and quantity pairs (p_1,q_1) and (p_2,q_2). The curve drawn in Figure 1 is one possible expected profit-maximizing bidding strategy. Extending this procedure to the case of more than two possible states of the world is straightforward, so long as distribution of the residual demand curves satisfies certain regularity conditions given in Wolak (2000). In this case, Firm A's expected profit-maximizing bid curve, S(p), is the function passing through all of the *ex post* profit-maximizing price and quantity pairs associated all of the possible residual demand curve realizations.

This logic has the following implication. Regardless of the residual demand realization, the following equation holds each hour of the day, h, and each supplier, j:

$$(P_h - MC_{jh})/P_h = -1/\epsilon_{hj}, \tag{1}$$

where P_h is the market price in hour h, MC_{jh} is the marginal cost of the highest cost MWh produced by firm j in hour h, and ϵ_{hj} is elasticity of the residual demand curve facing firm j during hour h evaluated at P_h. Mathematically, $\epsilon_{hj} = DR_{jh}'(P_h)\,(P_h / DR_{jh}(P_h))$. Define $L_{hj} = -1/\epsilon_{hj}$ as Lerner Index for firm j in hour h. By the logic of Figure 1, it is expected profit-maximizing for supplier j to submit a bid curve in hour h, $S_{jh}(p)$, such that all points of intersection between it and any possible residual demand curve firm j might face in that hour occur at prices where the equation (1) holds for that residual demand curve realization and resulting market-clearing price, P_h. If supplier j is able to find such a bid curve, then it cannot increase its expected profits by changing $S_{jh}(p)$, given the bids submitted by all of it competitors and all possible market demand realizations Q_h^d during hour h.

By this logic, the value of $L_{hj} = -1/\epsilon_{hj}$ is a measure of the unilateral market power that firm j possesses in hour h. I use bids submitted by all participants in the CAISO's real-time market to compute L_{hj} for each supplier j and all hours in my sample. The average hourly value of L_{hj} for each supplier for the period June 1 to September 30 is an annual measure of the amount unilateral market power possessed by that firm.

Although the conditions required for equation (1) to hold exactly for all possible residual demand realizations are not strictly valid for CAISO real-time market, deviations from equation (1) are unlikely to be economically significant. As discussed in Wolak (2000), the market rules may prohibit the firm from submitting a bid curve that is sufficiently flexible to intersect all possible residual demand curve realizations at their *ex post* profit-maximizing price and quantity pairs. Figure 4.1 of Wolak (2002) gives an example of how market rules might constraint the bid curves a supplier is able to submit for the case of the Australian electricity market. In this market, suppliers are able submit up to ten quantity bid increments per generating unit each half-hour of the day, subject to the constraints that all quantity increments are positive and they sum to less than or equal to the capacity of the generating unit.[1] Associated with each of these quantity increments are prices that must be set once per day.

As shown in Figure 4.1 of Wolak (2002), this restriction can constrain how much a firm's bid supply curves can vary across half-hours of the day. To assess the importance of this restriction on the ability of suppliers to set prices that satisfy equation (1) for all possible residual demand realizations for each half-hour of the day, Wolak (2000) compares the actual variable profits earned by a supplier in the Australia electricity market to the variable profits the supplier would earn if it were able to set the price that satisfies equation (1) for the realized residual demand curve for that half-hour. Using forward contract quantity information and the most plausible estimate of the marginal cost of supplying electricity from this firm's units, I found that averaged over my four month sample period, the ratio of the variable profits earned from prices determined by solving equation (1) and variable profits determined from actual production by the firm and the actual market clearing price was 1.12. This implies that the actual bids submitted this firm yielded market prices that produced variable profits that were approximately 90 percent of the variable profits that the firm could have obtained had it set prices that satisfied equation (1) for all hours for the bids submitted by all other market participants and the actual realization of demand for that half hour.

As noted in Wolak (2001), there are two possible explanations for this difference in variable profits. The first is that bidding rules constrain the ability of firms to set prices that satisfy equation (1) for all possible residual demand realizations. The second is that the actual bids submitted by market participants were not expected profit-maximizing. Wolak (2001) explores this hypothesis and computes estimates of the daily expected profit-maximizing bidding strategy for this firm for each day during the sample period and compares the realized profits assuming firms played this

[1] Electricity generating plants are typically composed of a number of generating units. For example, a 1500 Megawatt (MW) facility may be composed of three 500 MW units.

strategy instead of the bids they actually submitted. I find that roughly half of this difference between the variable profits at prices that satisfy equation (1) and actual variable profits, can be explained by the fact that the firm did not submit the expected profit-maximizing bidding strategy. Taken together these results suggest that an expected profit-maximizing firm operating in the Australian electricity market would not be overly constrained by the market rules from setting a price during each half-hour of the day that satisfies equation (1).

The CAISO's real-time market rules are even less likely to constrain the ability to suppliers to set prices that satisfy equation (1). Market participants are allowed to set 10 quantity increments during each hour of the day for each generation unit, but different from the Australian market they can change the price bids associated with each quantity bid on an hourly basis. This provides tremendous flexibility in how the bid curves of a market participant can vary across hours of the day. Further evidence for the view that suppliers to the CAISO real-time market are not overly constrained by the market rules is that they rarely, if ever, use all 10 bid-price/quantity increments during any hour of the day. For these reasons, equation (1) is likely to hold with a small enough error for L_{jh} to be a useful measure of firm-level market power. Because hourly deviations from equality in equation (1) are likely, we focus on the differences in average values L_{jh} across the years to assess changes in the amount of unilateral market power possessed by each supplier.

A factor that may cause hourly CAISO real-time prices to fail to satisfy equation (1) is the forward financial obligations of suppliers to provide electricity to the real-time market. As is demonstrated in Wolak (2000), a firm's forward financial contract position exerts an enormous influence on its expected profit-maximizing bidding behavior. This paper demonstrates that given a supplier's marginal cost curve virtually any bid supply curve can be rationalized as expected profit-maximizing by appropriate selection of a portfolio of forward contract positions. This fact was used by Wolak (2002) to show how the assumption of expected profit-maximizing behavior and an estimate of the firm's marginal cost curve could be used to recover credible estimates of the hourly forward financial contract position of a supplier.

BBW notes that approximately 85% of the electricity delivered in the CAISO control area during the first three years of the market was purchased in the California Power Exchange's (PX) day-ahead market with approximately 5 percent purchased in the CAISO's real-time market. The remaining quantity electricity was supplied through long-term contracts scheduled for delivery advance of the real-time market. Because the CAISO's real-time energy market is an imbalance market where suppliers and retailers buy and sell incremental and decremental amounts of energy relative to their day-ahead supply and demand commitments, the firms bidding into in the CAISO's real-time market do not have forward contract obligations to supply additional energy into this market. Consequently, forward contract obligations are not a factor causing equation (1) to fail for the CAISO real-time market.

III. Empirical Implementation

Computing the hourly value of the inverse of the residual demand elasticity facing each of the five large suppliers evaluated at a pre-specified price is relatively straightforward. The process involves first computing the aggregate demand for electricity in the CAISO's real-time energy market and subtracting from that the total amount supplied at this price by all market participants besides the firm j. This yields the value of the residual demand facing supplier j during hour h at that price. Computing the slope of the residual demand curve at the market-clearing price involves some approximation because, strictly speaking, all residual demand curves are step functions. Nevertheless, there are large number of steps of these residual demand curves, particularly in the neighborhood of the market-clearing price. To compute the slope of the residual demand curve at the hourly market-clearing price, I find the closest price above P_h such that the residual demand is less than the value at P_h. Call this $P_h(\text{low})$ and $DR_{jh}(P_h(\text{low}))$, the associated value of the residual demand. Next I find the closest price below P_h such that residual demand is greater than the value at P_h. Call this P_h(high) and $DR_{jh}(P_h(high))$ the associated value of the residual demand. The elasticity of the residual demand curve facing firm j during hour h at price P_h is equal to the arc elasticity computed as:

$$\epsilon_{jh} = \frac{DR_{jh}(P_h(high)) - DR_{jh}(P_h(low))}{P_h(high) - P_h(low))} \frac{P_h(high) + P_h(low))}{DR_{jh}(P_h(high)) + DR_{jh}(P_h(low))} \qquad (2)$$

I experimented with computing the slope of the residual demand curve using a first-difference approach setting P_h(low) and P_h(high) equal to a pre-specified value below and above P_h, such as \$1. However, this procedure does not guarantee that the difference between $DR_{jh}(P_h(high))$ and $DR_{jh}(P_h(low))$ is positive and therefore can produce zero values of ϵ_{jh}. Nevertheless, results using \$0.50, \$1 and \$5 to determine P_h(low) and P_h(high) did not produce noticeably different distributions of non-zero values L_{hj}.

A final issue associated with computing the residual demand elasticity is the fact that the CAISO's state-wide real-time market sometimes separates into a number of zonal markets when there is insufficient transmission capacity across regions of California to transfer all of the low-priced energy from one geographic area to other geographic areas. As noted in BBW (2002), initially the CAISO control area was divided into two congestion zones. Effective February 1, 2000, an additional congestion zone was added. When there is transmission congestion across zones, only suppliers with units located in the congestion zone can meet an incremental increase in the demand for energy in that congestion zone. This means that there are less suppliers able to meet an increase in demand in that congestion zone. For this reason, I would expect that the elasticity of a firm's residual demand curve when there is transmission congestion to be smaller in absolute value. Determining which units are able to supply additional demand within a congestion zone when there is transmission congestion is not straightforward. For this reason, the present analysis is restricted to hours with no transmission congestion. During the vast majority of hours of the sample period there is no congestion, although the fraction of hours with congestion in the transmission network in 2000 was significantly higher than in 1998 or 1999. For this reason, excluding hours with congestion should bias our results against finding higher average values firm-level Lerner indexes in 2000, because, as noted above, the firm-level Lerner index should be higher during hours with congestion because less suppliers are available to serve demand in any given congestion zone.

IV. Empirical Results

To measure the ability of suppliers to exercise market power by raising prices accurately, I must exclude hours when this should not occur. As noted in BBW, the cheapest natural gas-fired generating unit should not have a marginal cost less than \$20/MWh, even at the natural gas prices than existed during 1998 and 1999. By the late summer of 2000 natural gas prices were almost three times higher than during the summer of 1998 and 1999. Consequently, hours when the CAISO real-time price is below \$20/MWh is a very conservative estimate of the times when market power unlikely to be exercised. This cutoff price also biases against finding an increased level of unilateral market power in 2000, because higher natural gas prices during the summer of 2000 significantly raised the price below which market power was unlikely to be exercised. Higher values of the cutoff price yielded qualitatively similar results.

Table 1 lists the mean and standard error of minus one times the hourly inverse residual demand elasticity for each of the large suppliers to the California market. The results are quantitatively similar for all firms across the three years and none of the firm-level means are statistically significantly different from each other for the same year. For these two reasons, I report results by anonymous firm number, but not by firm name. Uniformly across the five large suppliers to the California market, I find that the mean hourly value of $L_{hj} = -1/\epsilon_{hj}$ for all hours without congestion and prices above $20/MWh are significantly higher in 2000 relative to 1998 and 1999. In addition, I also find that the mean value of L_{hj} for 1998 is slightly higher than the corresponding value for 1999 for each of the five suppliers–AES/Williams, Duke, Dynegy, Mirant and Reliant. The firm-level means for 2000 are significantly greater than those 1998 and 1999 at standard levels of statistical significance. For some of the firms, the means for 1998 are statistically significantly greater than the means for 1999.

These results are consistent with the BWW market-level results that found substantially larger amounts of market power was exercised during 2000 relative to 1998 or 1999. BBW also found larger amounts market power exercised during June to September of 1998 relative to those same months in 1999. Taken together the results in Table 1 and those in BBW answer the often asked question: "Why did suppliers withhold energy when spot prices were so high." The answer provided by Table 1 is: "Because it was in their unilateral profit-maximizing interest to do so, given the bids submitted by all other suppliers to the California market."

V. Conclusions and Directions for Future Research

The results in Table 1 show that collusive behavior on the part of suppliers to the California market is unnecessary to explain the enormous increase in market power exercised starting in June 2000 documented in BBW. The bidding behavior of all other suppliers to the California market during this time left AES/Williams, Duke, Dynegy, Mirant, and Reliant with residual demand curves that made it unilaterally expected-profit maximizing for each firm to bid to raise prices significantly in excess of the marginal cost of their highest cost unit operating. Although my results cannot rule out explanations involving collusive behavior by suppliers, these are unnecessary to rationalize differences in the extent of market power exercised in the California market across its first three years of operation.

There are a number of directions for future research. The first is incorporating hours when there is transmission congestion in the CAISO real-time market. Preliminary work along these lines confirms the intuition that the residual demand curves faced by the five large suppliers tend to be significantly less elastic during hours with congestion. A second direction for future research is to perform a similar analysis for the California PX day-ahead market. Because suppliers have the opportunity to sell their capacity in the CAISO ancillary services markets and the real-time energy market, measuring the extent of market power exercised in the California PX using this methodology is significantly more complicated.

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Figure 1: Computing the Expected Profit-Maximizing Bid Curve S(p)

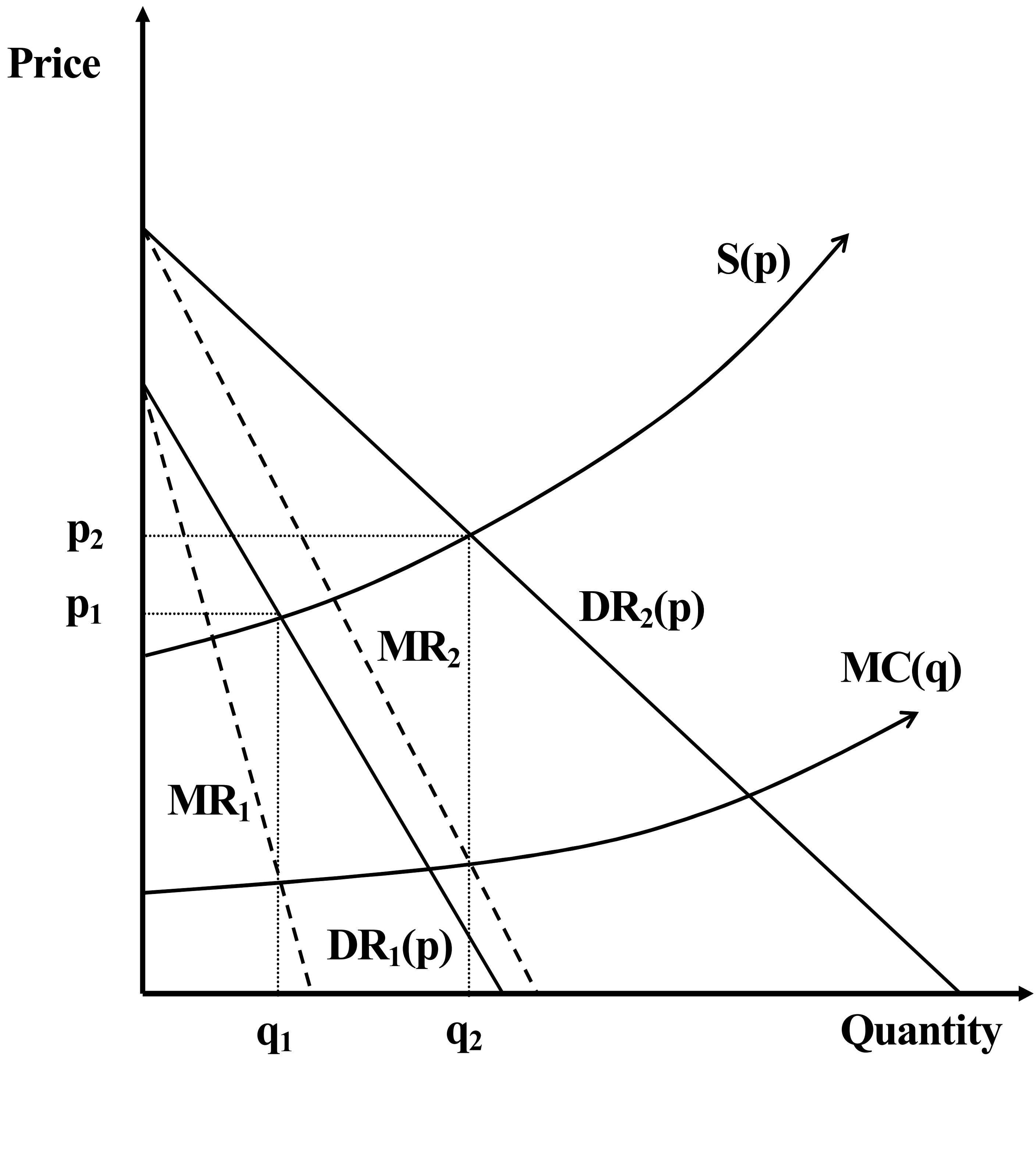

Table 1: Average Hourly Value of L_{hj} for June 1 to September 30 for Hours with Prices Above \$20/MWh			
Firm	1998 Mean (Standard Error)	1999 Mean (Standard Error)	2000 Mean (Standard Error)
1	0.045 (0.007)	0.035 (0.008)	0.164 (0.029)
2	0.039 (0.007)	0.028 (0.007)	0.164 (0.029)
3	0.054 (0.009)	0.032 (0.008)	0.095 (0.028)
4	0.065 (0.013)	0.032 (0.007)	0.189 (0.032)
5	0.055 (0.009)	0.035 (0.008)	0.161 (0.029)