Carnegie Mellon Electricity Industry Center
CEIC Working Paper 02-06
www.cmu.edu/ceic

The Model of Pivotal Oligopoly Applied to Electricity Markets

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September 2002

Abstract
Electricity industry is featured by the exceptionally inelastic demand, which has to be met by all means. Not meeting the demand may result in the power going down for all customers, the consequences of which are very costly. This feature leaves the participants of the electricity market much more room to manipulate the market and exercise the market power than in any other market. Inelastic demand is the reason why the usual measures of market concentration do not predict the possible market behavior in the electricity markets. Some new methods to assess the potential market power have been applied. They use the intuitive idea that the electricity market is concentrated and the risk of market power is very high whenever the largest supplier in the area owns the capacity, which is more than the supply margin during the peak hours. We provide theoretic justification for using the market concentration indices based on the supply margin. We developed the game-theoretic model of the uniform price auction with the capacity constrained generators. It gives the idea on the expected market price at different levels of demand. In particular, the model predicts that the expected market-clearing price depends on the minimum number of firms that need to act in concert to drive the price up. The significant market power can be exercised even when the supply margin is about the capacity of four to five largest generators. We propose to use the index of market concentration based on the minimum number of firms that may constitute the pivotal group at the given demand level.

1. Introduction

Deregulating the electricity industry was predicted to lower costs and prices. However, deregulated electricity markets facilitate the exercise of market power because of the physical properties of electricity: (1) Electricity is expensive to store and so supply and demand must match each millisecond. If demand exceeds supply, the system fails and no electricity is delivered. (2) Most load serving entities operate under conditions where their obligations to serve customers are long term while they purchase electricity one-hour to one-day in advance of delivery. (3) Retail customers face fixed prices that do not change as the wholesale price of electricity changes during the day and season. As a result, the short-run elasticity of residential demand is literally zero when price is above the fixed retail price. The utility must purchase sufficient electricity to satisfy customers, even if the wholesale price is much greater than the fixed retail price.

Until recently FERC's old rule assumed that a utility did not have market power if its uncommitted capacity was less than 20% of the market[1]. On November 20, 2001 FERC adopted the Supply Margin Assessment (SMA) screen instead of the old rule, which suggests that a utility does not have market power if its uncommitted capacity is less than the area capacity margin in the hours of peak demand. We show that even the much stricter new rule would not eliminate the risk of having market prices in excess of the marginal cost for significant parts of the year. No explicit collusion is required for several suppliers to raise the price. Our model suggests that the equilibrium strategy for each producer will be such that bidding above marginal cost has strictly positive probability. Therefore, the probability of having several suppliers simultaneously bid above marginal cost and, thus, having the market-clearing price above marginal cost is also positive.

We show that even the much stricter rule would not eliminate the risk of having market prices in excess of the marginal cost for significant parts of the year. FERC's SMA test rules out the situations when a single supplier in the market becomes pivotal, that is, when a single suppler could blackout the market by withholding its uncommitted capacity. When a pivotal supplier is free to offer power at a price up to the market price cap, they can demand the price cap in order to avoid blacking out the market. Without a significant demand response this bid would have to be accepted in the market and the market-clearing price would be set at this bid.

Even if all market participants meet the SMA and no supplier is pivotal, the expected market-clearing price may still be well above marginal cost. This happens when groups of more than one supplier become pivotal. In this situation several suppliers would have to bid above the marginal cost in order to raise the market-clearing price. Collusion among firms to raise market price is illegal under the Sherman antitrust act. However, no explicit collusion is required for several suppliers to raise the price. Our model suggests that the equilibrium strategy for each producer will be such that bidding above marginal cost has strictly positive probability. Therefore, the probability of having several suppliers simultaneously bid above marginal cost and, thus, having the market-clearing price above marginal cost is also positive.

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[1] Part of a generator's total capacity might be under a long-term contract and so could not be withheld. Thus, FERC focused on the uncommitted capacity. Instead of being content of this uncommitted capacity was less than 20% of the market, they now want it to be less that the difference between peak demand and supply.

The expected price approaches the marginal cost as the number of firms in the pivotal group increases. However, the expected price may still be highly elevated when two to four firms are in the pivotal group, that is, no firm is big enough to fail the FERC SMA test.

Market monitoring units at the Independent System Operators in California and PJM also admit the inconsistency of the usual measures of market concentration and prediction of market power exercise. Instead, California ISO and PJM use what is called a Residual Supplier Index, which is calculated as follows:

RSI = (Total Supply – Largest Seller's Supply)/(Total Demand)[(2)]

An RSI values less than 100% indicate that the largest supplier is pivotal and has the ability to set the market-clearing price. RSI values above 100% do not rule out the possibility that a few large suppliers jointly have market power (Sheffrin (2001)).

In this paper we explore a theoretical justification for using the SMA test and the RSI to measure the potential for exercising market power for single players and for the whole market. We also provide a link between the usual measures of market concentration, such as Herfindahl-Hirschman Index, and the indices based on the supply margin. In essence, our analysis shows that measures based on supply margin are more accurate indicators of market power potential than HHI when the demand is more than 1/3 of the capacity.

We model the expected market-clearing prices in the electricity markets depending on how many firms can jointly be pivotal. The modeling framework used in this paper comes from Edgeworth's (1897) extension of the Bertrand oligopoly model, in which the players compete placing simultaneous price bids. For a homogeneous good, the outcome of the Bertrand game is that each player bids at the marginal cost. Edgeworth suggested that when the sellers' capacities are limited and neither player's capacity alone is enough to meet the demand, no single price bid constitutes equilibrium for any player. The players' equilibrium strategies are represented by the probability distribution over the set of prices. Players do not stick to bidding at the marginal cost in equilibrium, occasionally bidding above it. Sticking to any price above the marginal cost also cannot be equilibrium since a rival could bid just below this price, making such strategy unattractive.

The assumptions of the Edgeworth model suits the electricity markets well. First, the capacity of each generator can be considered fixed, since capacity expansion is a more lengthy process than the frequency of the hourly electricity trades. Second, neither of the generators has enough capacity to meet the whole demand. Third, unlike the Cournot model, the Edgeworth model can deal with inelastic demand (Borenstein *et al* (1999), Stoft (2001)).

Finally, most critiques of the Bertrand-Edgeworth oligopoly focus on the inability of the model to handle inventories. Since the electricity industry has little or no inventory, this property is an asset in applying the Edgeworth model (Dudey (1992), Judd (1989)).

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[2] CAISO: Potential Economic Benefits to California Load from Expanding Path 15 – Year 2005 Prospect. Attachment 4

The main difference between the assumptions of the Edgeworth model and the rules of electricity markets is that in reality the generators may bid a different price on each generator, instead of the single bid that the Edgeworth model assumes. A extensive literature on the uniform price auctions, which is the most popular type of electricity market design, concludes that this discriminatory bidding may be crucial in giving participants an opportunity to exercise market power (Engelbrecht-Wiggans, R., Kahn, C.M. (1998), McAdams D. (2000), Joskow, P., Kahn, E. (2000)). In our model we restrict sellers to bidding a single price for all their capacity for the sake of simplification.

The remaining part of the paper is structured as follows: Part 2 describes the modified Edgeworth model, Part 3 shows how the model can be applied to the electricity markets and compares the results with the market behavior in California in 2000-2001. Part 4 provides concluding discussions on the limitations of the model.

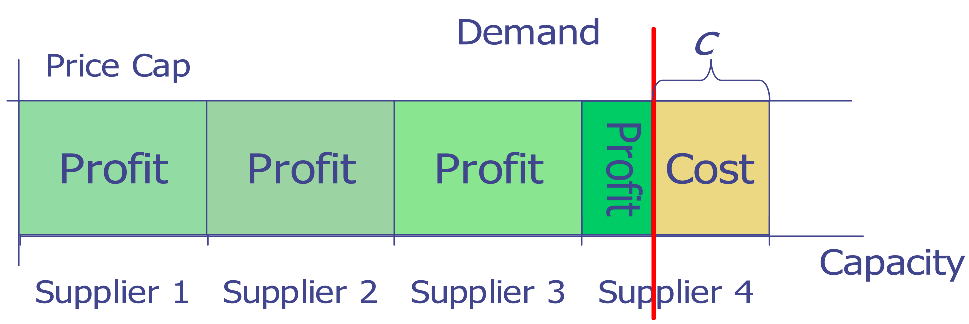
2. Model.

We model the market price resulting from the real-time uniform-price electricity auction as symmetric, mixed strategy, Nash equilibrium of a simultaneous move static game with full information. The goal is to estimate the relative importance of having one pivotal firm and more than one firm in a pivotal group. There are N identical firms in the market, each have zero marginal cost of generation and one unit of capacity. There is a price cap in the market, which can be set at 1 without loss of generality. Demand is completely inelastic.

Consider first the case of having one pivotal firm. That would mean that the demand is such, that the supply margin defined as the difference between the total industry capacity and the demand is less than the capacity of a single generator (Figure 1).

One pivotal firm

Figure 1. One firm in the pivotal group



We restrict the space of the strategies available for the sellers to two points: bid a "Low" price equal to marginal cost (p = 0) or a "High" price equal to the price cap (p = 1). This restriction simplifies the analysis greatly, not loosing generality[3]. The payoff of each firm depends on how many other firms bid “High”. The payoff matrix of each firm is as shown on Figure 1. The payoff depends on each firm’s own strategy “High” or “Low” and on the number of other firms who bid “High”.

Any firm gets zero profit if all firms (including itself) bid “Low”. If a firm bids “Low” and one or more other firms bid “High”, this firm gets a unit profit. This happens because under the uniform price auction the firm or firms who bid “High” set the market-clearing price, which has to be paid for all purchased power, including that from firms bidding “Low”.

Figure 2. Payoff matrix with one pivotal firm

		# of firms other than firm 1 bidding “High”			
		0	1	2	3
1	Low	0	1	1	1
	High	1-c	1-c/2	1-c/3	1-c/4

If a firm bids “High”, it sets the market-clearing price at one, but only part of its capacity is purchased, since those bidding “low” are rewarded. We refer to the “Cost” of bidding “High” as to the profit foregone by the firm who bids “High” compared to maximum profit the firm could get from receiving the price cap for all of its capacity. If a single firm is pivotal, this “Cost” is equivalent to the supply margin. We call this cost c and the payoff of a firm that bids “High” while the rest of the firms bid “Low” is $1-c$ (Figure **2**).

If two or more firms bid “High”, then the market takes only a part of the capacity of these firms. We assume that the system operator who runs this market uses the following rationing rule when more than one firm bids “High”. The power purchased from each generator that bid “High” is simply proportional to the capacity of this generator.

That is equivalent to splitting the “Cost” equally among these firms. That explains the payoffs of $1-c/2$, $1-c/3$ and $1-c/4$ of a firm that bids “High”, while 1, 2 and 3 other firms also correspondingly bid “High”.

Calculation of the Nash Equilibrium

In the symmetric Nash equilibrium each firm bids “High” with probability p. For this p to be equilibrium, each firm should have the same expected payoff from playing “High” and “Low”. That is, since the probability that k out of N - 1 firms simultaneously bid “High” is

$$C_{N-1}^{k}(1-p)^{N-1-k}p^{k}, \qquad (2.1)$$

[3] In fact, generators are free to bid different prices in the range from 0 to the cap for different parts of their capacity. However, it can be shown, that expansion of the set of possible price bids to more than two does not change the outcome significantly. Although the number of allowed price bids affects the expected market-clearing price, this dependence can be attributed to the lack of numerical precision provided by the binary strategy space.

p should be the root of the following polynomial:

$$(1-c)(1-p)^{N-1} - \frac{c}{2}C_{N-1}^{1}(1-p)^{N-2}p - \frac{c}{3}C_{N-1}^{2}(1-p)^{N-3}p^{2} - \ldots - \frac{c}{N}p^{N-1} = 0 \text{ ,(2.2)}$$

The probability of having the market-clearing price at the price cap is then equal to the joint probability of having at least one player bidding “High”:

$$P = 1-(1-p)^{N}, \qquad (2.3)$$

where p is the solution to the equation (2.2).

The probability of having the market price equal to the price cap (which can also be thought of the expected market-clearing price) when one firm is a pivotal supplier depends on the total number of firms and the exact position of the demand, which is characterized by c.

Figure 3. Expected market-clearing price as a function of number of firms (c = 0.7)

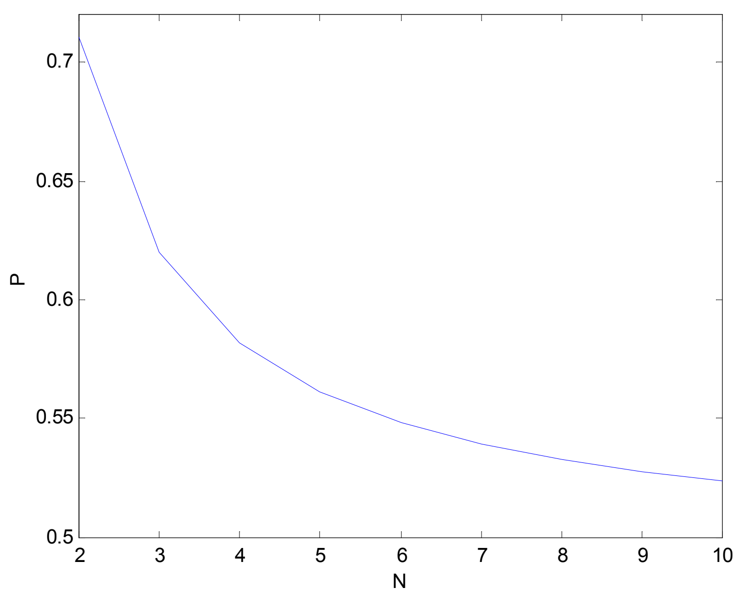
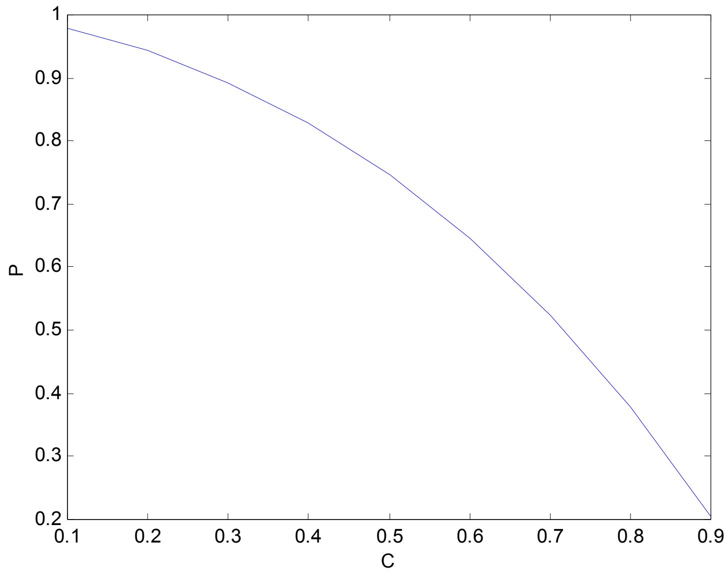


Figure 3 shows that the probability of market abuse decreases with the total number of players. However, as shown on Figure 4, the probability of having the high market price is much more dependent on the exact position of the demand within the interval where one firm is a pivotal supplier. This position is characterized by c.

Figure 4. Expected market-clearing price as a function of *c* (N = 10)

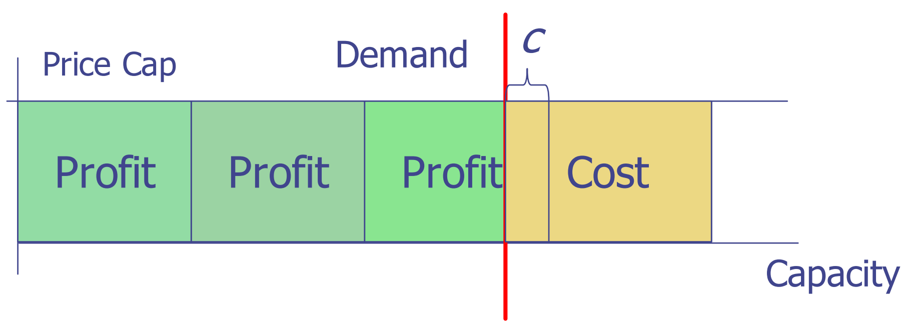


Conditional on *c*, the probability of having a high market price can be anywhere between zero and one in the case of one firm being a pivotal supplier.

Two or more firms form a pivotal group

When the demand is such that the supply margin exceeds the capacity of a single generator, a group of several generators is pivotal. The probability of market power abuse and the expected market price when two or more firms jointly become pivotal can be derived from the symmetric mixed Nash equilibrium.

Figure 5. Two firms in the pivotal group



The case of two firms in the pivotal group, that is, when the supply margin is between 2 and 1 (strictly speaking, Supply Margin $\in [1,2)$), is illustrated on Figure 5, and the resulting matrix of payoffs is shown on

Figure 6. Two firms are now required to bid "High" in order to get the market price equal to the price cap. When two or more firms bid "High", they earn the unit revenue for each of the

market participants, but share the "Cost" of bidding "High", which now is equal to the supply margin, $1+c$.

Figure 6. Payoff matrix when two firms are in the pivotal group

		# of firms other than firm 1 playing "High"			
		0	1	2	3
1	Low	0	0	1	1
	High	0	(1-c)/2	(2-c)/3	(3-c)/4

In general, if the number of firms in the pivotal group is *g* and the total number of firms is *N*, the probability of each firm's playing "High" is given by the polynomial:

$$\frac{1-c}{g}C_{N-1}^{g-1}(1-p)^{N-1}p^{g-1}-\frac{c+g-1}{g}C_{N-1}^{g-2}(1-p)^{N-1-g}p^{g}-\frac{c+g-1}{g+1}C_{N-1}^{g-3}(1-p)^{N-2-g}p^{g+1}-...-\frac{c+g-1}{N}p^{N-1}=0 \quad (2.4$$

where *c* is given by the difference between the supply margin and *g*.

$$\text{Supply Margin} = c+g-1$$

The probability of having the market price equal to the price cap is then

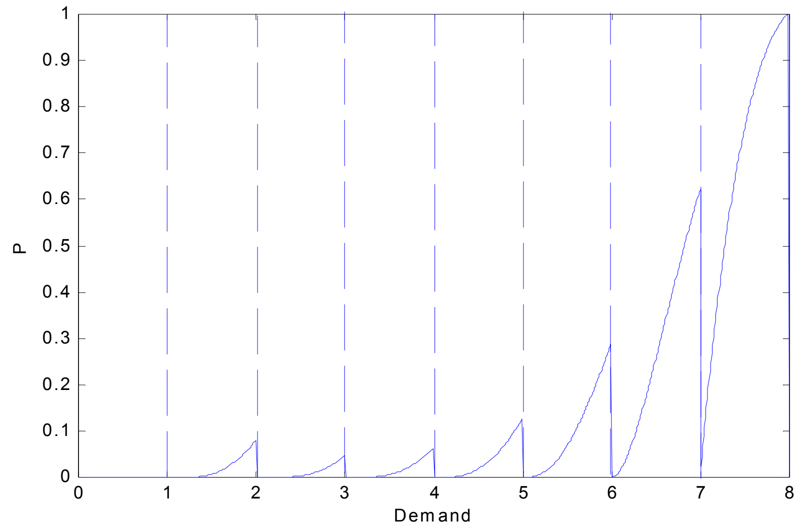
$$P=C_N^g(1-p)^{N-g}p^g+C_N^g(1-p)^{N-g-1}p^{g+1}+...+C_N^N p^N \qquad (2.5)$$

The polynomial (2.4) has only one real root in the interval [0, 1], which is taken for the solution of the mixed strategy Nash equilibrium. Now we can reconstruct the probability of market abuse for all demand levels. The resulting "supply function" is plotted on Figure 7. In this figure there are 8 firms and each firm has a capacity of one.

When the demand is at the capacity margin (8) the probability of having the market price at the cap is one. The probability of high price decreases as the supply margin expands. This decrease is not a uniform, though. The graph of the probability of high price has discontinuities every time the demand moves to a next demand level.

For instance, when demand changes from 6.99 to 7.01 the number of firms in the pivotal group changes from 2 to 1 and *c* changes from nearly zero to nearly 1. When *c* is close to one at the demand of 7.01, bidding "Low" becomes a dominating strategy. Bidding "High" does not give any extra profit over bidding "Low" in any state. When *c* is close to zero as it is at the demand level of 6.99, bidding "High" gives a higher profit than bidding "Low" when one other generator bids "High". C close to zero means that bidding "Low" gives smaller or the same profit in all other states allowing for the equilibrium mixed strategy with non-zero probability of bidding "High".

Figure 7. Expected market price as a function of the system demand



3. Application

The probabilities plotted on Figure 7 can be used to predict the likelihood and the extent of market power exercised in each demand interval. A natural way would be to take average probabilities within each demand interval for the specific number of firms in the pivotal group. However, taking maximum probabilities in each demand interval may prove to be more reasonable. First, a test based on such probabilities would have higher sensitivity. Second, it can be shown that, in the case of asymmetric capacities, the maximum probabilities of having the high market price in each demand interval coincide with those in the symmetric case. For the intermediate probabilities this may not be true.

Figure 8. Maximum and average probabilities of market power abuse in demand intervals

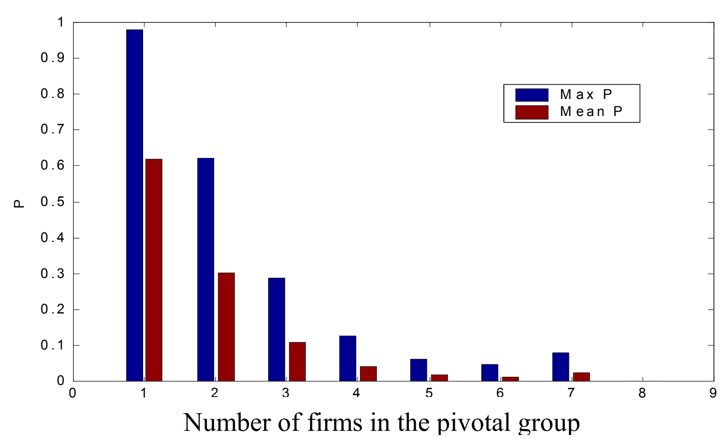


Figure 8 shows maximum and average probabilities of having the market-clearing price at the cap depending on how many firms are in the pivotal group.

The probabilities obtained in the model can be used to predict the relation between the average price to cost ratios in different demand categories. Indeed, according to the model, the expected price-cost markup is proportional to the probabilities of having the market-clearing price equal to the price cap.

Supply Margin and HHI

The model presented above suggests that the probability of market tacit collusion depends on both the total number of firms and the number of firms in the pivotal group. We examine the contribution of these two factors to see at what conditions the number of firms in the pivotal group is a more important indicator of the market power potential than the total number of firms. This would allow making a link between the conventional measures of market concentration like HHI and the indices based on the supply margin, as well as determining the domains where one or the other is best applied.

For that purpose we construct the matrix of maximum probabilities of market power exercise at different total number of firms and demand levels correspondent to different number of firms in the pivotal group.

$$P_{n,k}, k \leq n-1,$$

where n - total number of firms and k - number of firms in the pivotal group. We further take the partial differences $P^N_{n,k} = P_{n,k} - P_{n+1,k}$ and $P^g_{n,k} = P_{n,k} - P_{n,k+1}$, which characterize the decrease of the probability of market exercise when the total number of firms and the number of firms in the pivotal group is increased by one.

Figure 9. Predictive power of the total number of firms and the number of firms in the pivotal group

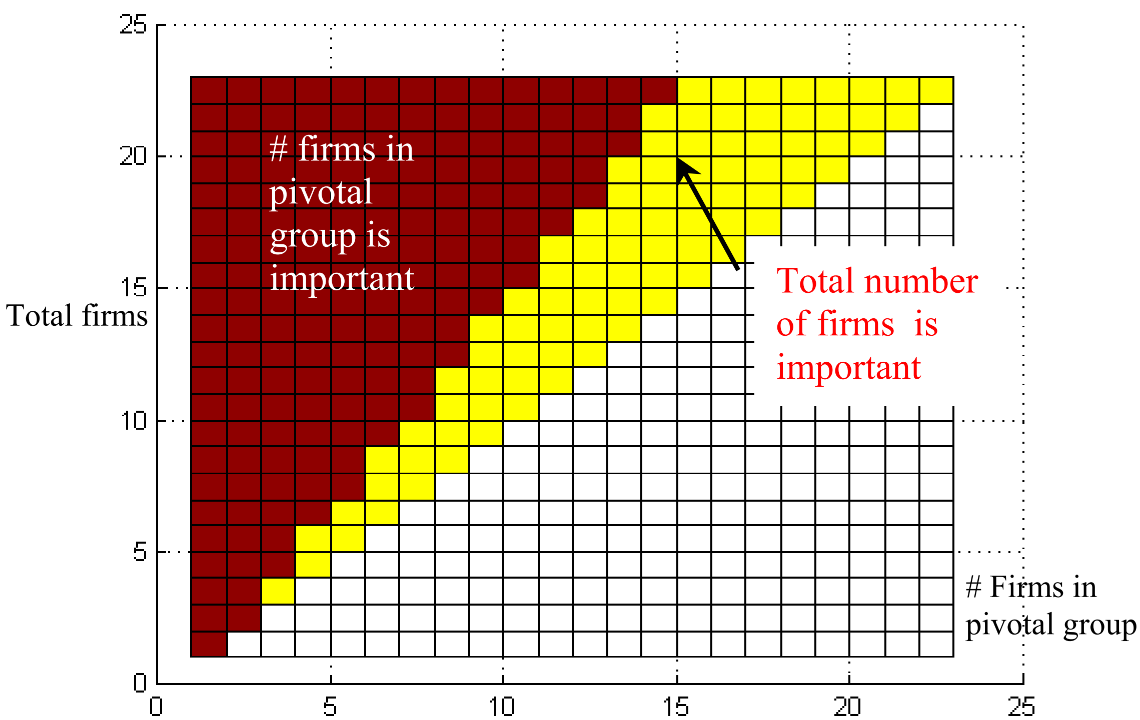
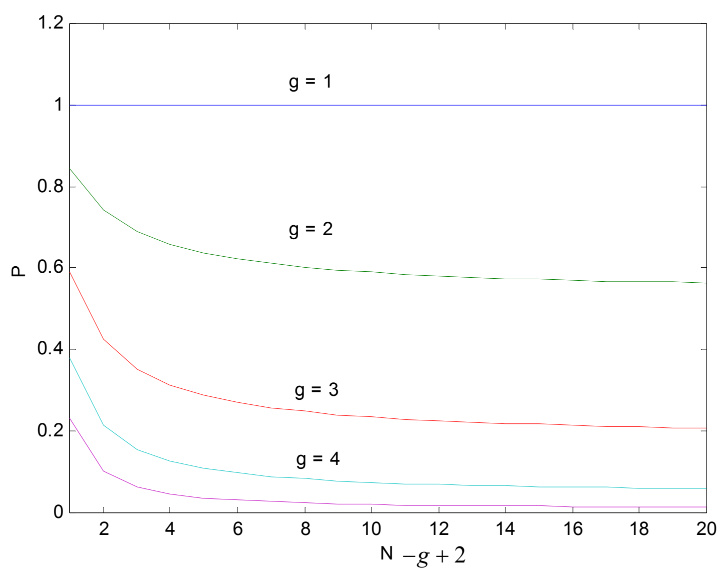


Figure 9 shows the total number of equally sized firms in the market and the number of firms in the pivot group. When there are N firms in the market and g firms in the pivot group, the total demand is assumed to be $N - g + 1$ ($c = 0$ to achieve the maximum probability of market power abuse in each group). Only the area of the graph where $g > N + 1$ is relevant. The dark shaded area corresponds to the situations where the number of firms in the pivot group has more effect on the probability of high market price than the total number of firms. That is, the supply margin model predicts market power better than the conventional measures of market concentration like the Herfindahl-Hirschman Index. That happens at high demands level, at which $g < 2N/3+1$. In the light-shaded area corresponding to the demand levels such that $2N/3+1<g<N+1,$ where the conventional HHI predicts better, the probability of getting the price rising to the price cap is trivial according to the model.

Figure **10** shows the probabilities $P_{n,k}$ so that each curve represents the dependence of the maximum probability of market exercise ($c = 0$) on the total number of firms in each group. Since we can have one pivotal firm only when the total number of firms is at least two, two pivotal firms when total firms are at least three and so on, we plot these curves against $N - g + 2$ to stack all the curves to the left.

Figure 10. Expected market price depending on N and the number of firms n pivotal group



California

In this section we compare the prediction of the model with the prices observed in California ISO from June 2000 to June 2001. Since no contracts were allowed in California ISO area, we assume that all thermal capacity is uncommitted and we net out the hydro and nuclear capacity from both the load and firms' capacity. Most of California thermal capacity is concentrated in 11 largest firms (Table 1). The capacity HHI is 1,248, which corresponds to having 8 identical firms.

Figure 11 shows the max and mean expected market prices predicted by the model and actual average market prices in California from June 16, 2000 to December 31, 2000 in the demand intervals correspondent to different numbers of firms in the pivotal group. We use normalized market price to make the data comparable to the model predictions:

$$P_{norm} = \frac{\text{Price} - \text{Cost}}{\text{Cap} - \text{Cost}}$$

The operating area marginal cost curve was estimated using the data on heat rates and emission rates of California gas-fired plants, prices of gas and the NO_x credits. The hourly marginal cost was identified by intersecting the hourly demand with the area marginal cost curve.

The number of firms in the pivotal group was calculated in the following way: whenever the supply margin was less or equal to the capacity of the largest generator, one pivotal firm was assumed; when the supply margin was greater than the capacity of the largest generator, but still less than the capacity of two largest generators, two pivotal firms were assumed, etc.

Table 1. California ISO thermal capacity

Largest Generators	Capacity
AES NUGs	4860.25
Reliant Energy Power Gen	4018.83
Los Angeles City of	3268.21
Southern Energy Inc	3165.75
NRG Energy	3019.71
Duke Energy Power Services	2880.95
Calpine	1828.39
Port of San Diego	732.50
Pacific Gas & Electric Co	530.75
BP Amoco	514.80
Imperial Irrigation District	398.50

In Figure 11, the actual prices were between the max and mean predicted prices for pivotal groups with one, two and seven firms. When demand corresponded to having three to six firms in the pivotal group, the actual price was about the maximum predicted price. Thus, generating firms were able to raise price more than the Nash equilibrium predicts, indicating tacit or real collusion in these situations or other situations not accounted for in this model.

Figure 11. Modeled and actual prices for California ISO June 2000 to December 2000

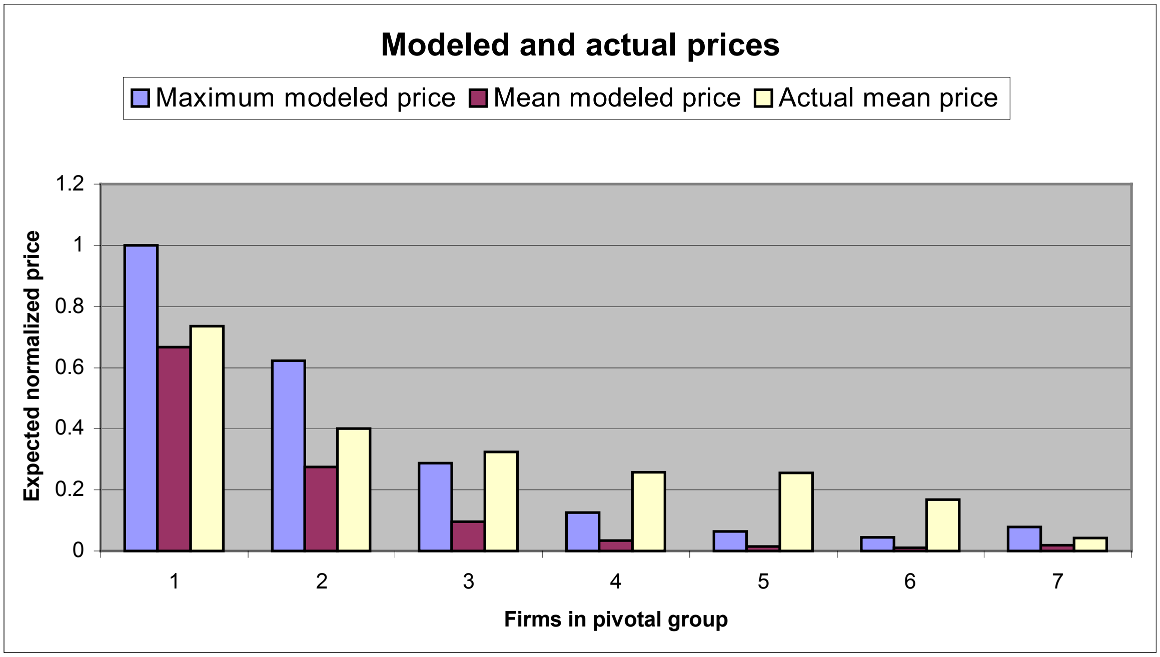


Table 2 uses the load duration curve in California ISO to calculate the number of hours when the demand is in the intervals with one to six firms in the pivotal group. Although the risk of market power exercise is much lower with two pivotal firms than with one, the demand levels corresponding to the having one pivotal firm are less often than the demand corresponding to two pivotal firms. Between June 2000 and June 2001 there were 612 hours with one pivotal firm and 1,285 hours with two pivotal firms.

Multiplying these hours by the probabilities suggested by the model one can get the annual expected number of hours of market power abuse in each demand interval. High demand hours with a single pivotal firm may result in 612 hours of excessive market prices, while demand levels with two and three pivotal firms may result on average in 797 and 616 hours of excessive market prices correspondently. Demand with more than three pivotal firms results in significantly less hours of high prices in a year.

Table 2. Expected hours of having market power exercise in California 2000-2001 by demand intervals

	Number of pivotal firms					
	1	***2***	***3***	***4***	***5***	***6***
Hours in the group	612	1285	2125	1785	1561	1427
Prob of high price	1	0.62	0.29	0.13	0.08	0.06
Expected hrs of high price	612	796.7	616.25	232.05	124.88	85.62

Supply Margin HHI

Having in mind the implications of the above model we would like to suggest a new index to measure market concentration in the electricity markets, which would adequately predict the potential for market power. We suggest that the new index be based on the supply margin and the number of the pivotal firms and also resemble the conventional HHI in the sense that the index value is proportional to the possible extent of market power exercise.

$$\text{Supply Margin HHI } = \frac{10{,}000}{\text{Number of firms in pivotal group}}$$

In the hours when there is a single pivotal firm the Supply Margin HHI would be 10,000, a number, which represents monopoly power according to the conventional HHI. When two firms are pivotal, SMHHI becomes 5,000, which on the one hand equivalent to a duopoly in the sense of the conventional HHI and, on the other hand represents almost a twofold decrease in the risk of market power predicted by the model.

Taking the average hourly Supply Margin HHI over the year one can assess the overall concentration in the market and the risk of market power. Thus, the SMHHI in California ISO area in 2000 – 2001 in the situation of the low water levels is 3,364 representing a highly concentrated market. When the water levels are normal, the SMHHI becomes 2,031, which although is much less, still represents a relatively concentrated market.

4. Conclusion

Our model provides the rationale for using measures of market concentration based on the relation between the size of the suppliers and the supply margin in electricity markets instead of the usual measures of market concentration based on market share. The model suggests that the market share based measures of market concentration can be relevant in electricity markets only at very low levels of demand and high supply margins.

The symmetric model suggests that market power gradually declines with the number of firms that can jointly be pivotal. Having a single pivotal firm gives that firm high market power. The model quantifies the probability of realizing a high price given the number of firms in the market and the number of firms in the pivotal group.

The model allows us to construct an index similar to the conventional HHI based on the supply margin and the number of pivotal firms. Such index would be a better predictor of market power in electricity markets.

We make certain assumptions for the model presented here, which may significantly affect the results:

1. The model presented here suggests that the sellers have identical capacity, which definitely does not hold in the real life. A symmetric game is much easier to solve numerically. The asymmetric game is likely to have multiple equilibria; since the symmetry principle will not work any longer, it will be unclear which equilibrium to choose. However, some lessons from the symmetric model can be transferred to the asymmetric without change. The highest probability of having the price at the cap would be the same in the asymmetric game as in the symmetric. This can be easily seen from the fact that the payoff matrix for any number of firms in the pivotal group and $c = 0$ is the same for both symmetric and asymmetric games. As c increases the probability of getting high price will likely be still less than at $c = 0$ but may be higher than in the symmetric game. This may happen because the total number of combinations of pivotal firms will decrease, increasing the probability of high price over the symmetric game. The

discontinuity in the relation between the expected market price and the demand may also disappear when the symmetry assumption is lifted.

2. We limit the set of strategies available to the sellers allowing them to bid either marginal cost or the cap price over all their capacity. Allowing only two levels of price bids but slightly increases the expected market price compared to the cases with more choice for bidding. We checked that fact on a two-player example.
3. As it was mentioned above, the inability to bid differently for different parts of one's capacity might be a significant simplification over the real life. What happens to the market price when the set of strategies is extended in this direction still needs to be checked.
4. The model presented here assumes that the marginal cost is zero for all the capacity of all suppliers. The fact that the marginal costs are different for different sellers and for different parts of sellers' capacity may be not very important if the highest marginal cost is still much less than the price cap. In this situation approximating all marginal costs at zero makes perfect sense. However, as the price cap approaches the marginal cost, the assumption of zero marginal costs will likely become the source of significant inaccuracy. When the price cap is equal to the highest marginal cost (as it was set by FERC order of June 19, 2000), a different mechanism will likely to be driving the suppliers to bid above their marginal costs. The sellers would economically withhold their capacity by bidding high on it in order to shift the price up along the marginal cost curve and earn the extra profit on the remaining capacity (Joskow, Kahn (2000), Perekhodtsev, Lave (2001)). It is unclear how the two mechanisms that drive the economic withholding would work together in the cases of intermediate price cap.
5. In the model presented here the uniform auction design is assumed. Although, this design is very popular in the electricity markets, some markets operate differently following the pay-as-you-bid auction scheme. There are ongoing debates on whether the two auctions provide the identical outcome (Cornell ???). Checking the difference of the model behavior under different auction designs may be one of the directions of future research.

References

Dudey, M. (1992) “Dynamic Edgeworth-Bertrand Competition”, *Quaterly Journal of Economics* 107:4, 1461-77

Judd, K. (1989) “Cournot versus Bertrand: a dynamic resolution”, mimeo

McAdams D. (2000). ”Collusive-Seeming Equilibria in the Uniform-Price Auction” mimeo

Joskow, P., Kahn, E. (2000) ”A Quantitative Analysis of Pricing Behavior in California’s Wholesale Electricity Market During Summer 2000” mimeo

Engelbrecht-Wiggans, R., Kahn, C.M. (1998). ”Multi-Unit Auctions With Uniform Prices” *Economic Theory* 12: 227-258

Stoft, S. (2001) “An Analysis of FERC’s Hub-and-Spoke Market Power Screen”, mimeo

Borenstein, S., Bushnell, J., Knittel, C. (1999) “Market Power in Electricity Markets: Beyond Concentration Measures”, POWER working paper PWP-059r

Tirole, J. (1988) *The Theory of Industrial Organization*, Cambridge MA, MIT Press

Sheffrin, A. (2001) “Critical Actions Necessary for Effective Market Monitoring”, Department of Market Analysis, California ISO

Perekhodtsev, D. Lave, L.B. (2001) “Capacity Withholding Equilibrium in Wholesale Electricity Markets”, Carnegie Mellon Electricity Industry Center, CEIC-01-01, http://wpweb2k.gsia.cmu.edu/ceic/publications.htm