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# "Analytic and Experimentally-Derived Estimates of Market Power in Deregulated Electricity Systems: Policy Implications for the Management and Institutional Evolution of the Industry"

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# "Analytic and Experimentally-Derived Estimates of Market Power in Deregulated Electricity Systems: Policy Implications for the Management and Institutional Evolution of the Industry"

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### *Abstract*

*Previous experimental and game-theoretic analyses of deregulated electricity markets suggest that communities having four or less effective suppliers, either because of transmission constraints or load characteristics, or retail customers facing suppliers or marketing agents having more than seventy percent of the region's market, are likely to experience prices well above competitive levels.*

*While state regulatory bodies may be able to forestall the onset of retail wheeling and non-regulated retail energy pricing until a single supplier does not dominate initial market shares, it is more difficult to mute the exercise of market power by generators serving electrically isolated load pockets. And in both instances, if the accrual of some excess profits by initial, non-regulated suppliers are not tolerated, then little incentive will have been provided for competitors to enter the market and for more efficient technologies to evolve.*

*Estimates are provided in this analysis of the circumstances for and the extent and duration of the exercise of market power. When combined with the present absence of incentives to build transmission lines that would reduce bottlenecks and the existing utilities' insistence upon full recovery of stranded costs through line charges and access fees, the powerful incentives to develop distributed generation are highlighted.*

## 1. Introduction

An electricity supply industry with deregulated generation will allow some generators to exercise market-power at particular locations. In a static equilibrium analysis for New York State, Hobbs and Schuler, 1985, [1] estimated that this market power would result in bulk power prices for service in certain locations that are appreciably above marginal costs of production and also above the prices allowed under regulation (10 to 15 percent in the short-run). This market power is most likely to be exercised in locations where limited transmission capacity restricts the number of generators that can effectively supply that area's distribution system. Since transmission is the one aspect of the electricity supply system that continues to exhibit enormous decreasing unit costs as the capacity of a line increases, transmission retains natural monopoly characteristics and is therefore the fundamental source of future market power.

However, in a recent set of conceptual analyses, Schuler 1998, [2] and [3], has identified a second likely source of market power that may be exercised by marketing firms selling to end-users of electricity after retail wheeling is inauguarated. In this case, the source of the monopoly power is mostly self-inflicted by consumers' observed behavior of being slow to respond to the apparently favorable prices offered by new venders in deregulated markets. Thus incumbent suppliers with large initial market shares may find it profitable to continue to offer prices to customers that are significantly above competitive levels if the rate of erosion of their market shares is sufficiently slow.

The conceptual support for these assertions is developed more fully in this analysis; in particular, game-theoretic models of several generators selling into an auction with a pre-specified, fixed demand quantity are developed, and the opportunity for exercising market power in repeated auctions (the example is bulk power auctions which will have Monday morning at 9AM repeated 52 times per year) is demonstrated. These theoretical results for bulk power auctions are then compared with experimental results developed in a market laboratory at Cornell (see the paper by

Bernard, et. al., 1998, [4]).

When the previously estimated potential retail mark-ups in price due to lagged customer response are considered together with generation profits, some regions may experience substantial increases in their electricity prices; however, other areas ringed with a number of generators and with minimal transmission bottlenecks may see lower prices.

Besides reducing substantially concerns over the level of "stranded costs" that the former regulated electric utilities need to recover through added transmission and distribution charges, this analysis highlights opportunities for substantial technological innovation in distributed generation that would be offered by the exercise of market power. Alternatively, were additional transmission capacity developed to meet the demands for economic-based dispatch, much of the generation-based market-power would be reduced by opening previously constrained areas to a larger number of competitors This in turn would reduce the incentives for developing distributed generation technologies.

## 2. Potential for Market Power in Bulk Power Auctions

### Case A:

Begin by considering two generators selling into a fixed quantity auction where each supplier has less available capacity than the total market demand. This case is analagous to two generators in an isolated load pocket where each supplier will then be in a "must run" situation. For numerical convenience, normalize each generator's price mark-up over marginal cost of production by the difference between a monopoly price and marginal cost. In this way, $0 \leq p \leq 1$, where p is the normalized price, and $p = 0$ signifies a price at marginal cost, $p = 1$ represents the perfect monopoly price. Then in a simple, single period game where successful bidders are paid the last accepted offer, assume that both generators have the same marginal costs of production, and that each can serve at most 75 percent of the total market.

Then–

$$\pi^i = \bar{p}\; s^i \qquad (1)$$

Where: $s^i = .25$ if $p^i > p^j$
$= .5$ if $p^i = p^j$
$= .75$ if $p^i < p^j$
$\bar{p} = \text{Max.}(p^i, p^j)$ = Market-clearing price.
$p^{i,j}$ = Normalized price of generator i,j.
$s^{i,j}$ = Market share of generator i,j

Table 1. Payoff Matrix for Two Generators Bidding in a Single Period, Fixed Quantity Auction, Each with Capacity to Serve 75 Percent of Demand. Market Clears at Last Accepted Offer. [p ∊ 0;.25; .5; .75; 1.0]

Firm 2's payoff in NE corner; 1's payoff in SW corner

| $p^1$ \ $p^2$ | 0 | .25 | .5 | .75 | 1.0 |
|---|---|---|---|---|---|
| 0 | 0<br>0 | .063<br>.188 | .125<br>.375 | .188<br>.563 | .25<br>.75 **N** |
| .25 | .188<br>.063 | .125<br>.125 | .125<br>.375 | .188<br>.563 | .25<br>.75 **N** |
| .5 | .375<br>.125 | .375<br>.125 | .25<br>.25 | .188<br>.563 | .25<br>.75 |
| .75 | .563<br>.188 | .563<br>.188 | .563<br>.188 | .375<br>.375 | .25<br>.75 |
| 1.0 | .75<br>.25 **N** | .75<br>.25 **N** | .75<br>.25 | .75<br>.25 | .5<br>.5 |

N = Nash Equilibria

For this illustration, a payoff matrix is shown in Table 1 where each firm can select five discrete prices, and there are multiple Nash equilibria. But all equilibria result in a market clearing price at the level of a pure monopolist ($\bar{p} = 1$), since one of the parties will be in the position where some of its generation is required to satisfy market demand, and therefore it will offer the monopoly reservation price. With more than two suppliers serving a load pocket, so long as some generation is required from every supplier in order to meet the area's demand (all are must-run units), then similar results can be expected where at least one of the suppliers will offer a monopoly price, thereby setting the market-clearing price at $\bar{p} = 1$.

### Case B:

In the case of a fixed demand auction where one or more suppliers can be squeezed out of the market entirely if they offer too high a price because the entire demand can be met by the competitor's generation, a more traditional auction result with prices driven below the monopoly level might be expected. If each of two suppliers has sufficient capacity to serve the entire market demand, then the profit relationship is as follows:

$$\pi^i = \bar{p} \; s^i \tag{2}$$

Where: $s^i = 0$ if $p^i > p^j$
$= .5$ if $p^i = p^j$
$= 1.0$ if $p^i < p^j$
$\bar{p} = \text{Min}(p^i;p^j) =$ Market-clearing price

If a single period auction is again considered with $p^{i,j} \in$ [0; .25; .5; .75; 1.0] the payoff matrix is shown in Table 2. In this case there is a stable Nash equilibrium with both generators offering p = .25 and a quasi-stable result where both firms offer p = .5. In this second quasi-stable state, without introducing additional behavioral rules, each generator sees its own reward, in isolation, to be the same with p = .25 or p = .5. For those generators who experiment with price, there is a good chance that the $p^1 = p^2 = .5$ equilibrium may collapse to $p^1 = p^2 = .25$. And although Pareto superior outcomes exist (both players can do better) with generators charging a price of .75 or 1.0, neither of these point represent a Nash Equilibrium since one player always has an incentive to defect.

Table 2. Payoff Matrix for Two Generators Bidding in a Single Period, Fixed Quantity Auction, Each with Capacity to Serve the Entire Market. Market Clears at Last Accepted Bid. [p ∊ 0; .25; .5; 75; 1.0]

Firm 2's payoff in NE corner; 1's payoff in SW corner

| $p^1$ \ $p^2$ | 0 | .25 | .5 | .75 | 1.0 |
|---|---|---|---|---|---|
| 0 | 0 / 0 | 0 / 0 | 0 / 0 | 0 / 0 | 0 / 0 |
| .25 | 0 / 0 | .125 / .125 **N** | 0 / .25 | 0 / .25 | 0 / .25 |
| .50 | 0 / 0 | .25 / 0 | .25 / .25 **N** | 0 / .5 | 0 / .5 |
| .75 | 0 / 0 | .25 / 0 | .5 / 0 | .375 / .375 | 0 / .75 |
| 1.0 | 0 / 0 | .25 / 0 | .5 / 0 | .75 / 0 | .5 / .5 **PS** |

N = Nash Equilibria PS = Pareto Superior Solution

While the market-clearing prices in this one period auction, where all suppliers are not guaranteed some portion of the market because of substantial excess capacity, are above marginal cost, they are not far above.

However, in auctions for generation in electricity markets, similar auctions are expected to be repeated many times per year. As an example the demands at 9AM on weekday mornings may be quite similar, five times a week, twenty-one times per month and 260 times per year. While seasonal and weather conditions may alter the demand, and operating and maintenance requirements may change the available supply, many of these variables may also be predictable with reasonable accuracy, and so the participants in the market may come to form reasonable expectations about the plans of other suppliers and to alter their bidding strategies accordingly. Furthermore, over time the suppliers will have ample opportunity to test the validity of their conjectures regarding the behavior of their competitors and to adjust their own expectations and offers in response to these observations.

These are precisely the conditions that Langlois and Sachs, 1993, [5] lay out in their analysis of repeated games of infinite duration. In that case, since the players consider not only the profitability of their current period's offer in the current period, but also how it might influence the prices offered by competitors in future periods, and in turn the effect of those future offers on their own sequence of offers in the future, and their consequent future profits, the single period paradigm is not applicable. Langlois and Sachs describe a unifying, "benefit-denial" principle that explains why no profit-maximizing player in these circumstances would deem it beneficial to defect, individually, from offering the monopoly price. Were one supplier to do so, they would obviously profit in the short run by garnering additional market share from their competitors, but the obvious response by their competitors, who are each also trying to maximize their individual profits, would be to lower their prices. In the long-run the potential price cutter can only anticipate a short-run gain resulting from their price cut and a loss over the very long-run resulting from subsequent market shares close to the original division, but served at a significantly lower price. In a game of infinite duration, Langlois and Sachs show that in net present value terms, no individual supplier can expect to earn profits greater than they would by offering the monopoly price in each and every period, no matter how deeply they undercut their competitors' offers in the short-run. Furthermore, no collusive arrangement is necessary to achieve this outcome, individually-determined, enlightened self-interest is all that is required.

What Langlois and Sachs don't consider is the cost to each individual supplier of processing all of the historic information about prices of their competitors, and how the number of participants in any market compounds the complexity and cost of those computations (which however is much diminished by modern computational power). Are there some large number of potential suppliers at which it is simply not worth while incurring the computational cost since it may out weigh the benefit of likely future profits? And, of course, most participants in even a repeated auction don't view their time horizons as infinite. At what critical finite time interval between one play and infinity does the benefit-denial principle no longer apply? Furthermore, in most proposed auctions for bulk power supplies, only the market-clearing price is revealed, not the offers of all participants, so each supplier is likely to know the offer of at most one other participant at any time period.

To illustrate the benefit denial principle, consider a five period repeated auction into a published fixed demand that can be served entirely by two competitors with equivalent costs. Using the market allocation scheme of equation 2, if each of the two parties begins to develop price strategies by assuming both parties will charge the pure monopoly price ( p = 1 ), which is the Pareto Superior Solution, and then if supplier one explores sequentially the profitability of defecting, the expected profits are summarized in Table 3, based upon a set of consistent conjectures about the competitor's price response. So long as each firm holds to the monopoly price, each expects the other to continue to do so into the next period. However, if one firm undercuts the monopoly price, they can expect the other firm to do so in the subsequent period, and once that implicit trust is broken, they can expect that the best they can do is to play the single period game laid out in Table 2 with $p^1$, $p^2$ = .25, $s^1$, $s^2$ = .5 and $\pi^1$, $\pi^2$ = .125. In this illustration, the initial defection price is set at .75 < p* = 1 since this yields the maximum expected gain from defection with the competitor's response lagged by one period. If in making this optimistic assumption about the gains from defection that defection still does not seem to be profitable, then actual price-cutting may be even less likely to occur.

Table 3. Illustration of Benefit Denial Principle with Two Identical Suppliers Bidding into a Fixed Quantity Auction in Each of Five Periods. [p ∊ 0; .25; .5; .75; 1.0]

$p_0^* = 1, 1, 1, 1, 1,$

$$E(p_{t+1}^2) = \begin{cases} p_t^1 & \text{if } p_t^1 = 1 \\ \le p_t^1 & \text{if } p_t^1 < 1 \end{cases}$$

$\pi_0^* = .5, .5, .5, .5, .5 = 2.5$
(joint monopoly profit)

| Defection Period | Price Vectors | $E(\pi^1)$ | $E(\pi^1) - \pi_0^*$ |
|---|---|---|---|
| t = 1 | $p^1$ = .75, .25, .25, .25, .25<br>$E(p^2)$ = 1, .25, .25, .25, .25 | .75 + .125 + .125 + .125 + .125 = 1.25 | -1.25 |
| t= 2 | $p^1$ = 1, .75, .25, .25, .25<br>$E(p^2)$ = 1, 1, .25, .25, .25 | .5 + .75 + .125 + .125 + .125 = 1.5 | -1.0 |
| t=3 | $p^1$ = 1, 1, .75, .25, .25<br>$E(p^2)$ = 1, 1, 1, .25, .25 | .5 + .5 + .75 + .125 + .125 = 2.0 | -0.5 |
| t = 4 | $p^1$ = 1, 1, 1, .75, .25<br>$E(p^2)$ = 1, 1, 1, 1, .25 | .5 + .5 + .5 + .75 + .125 = 2.375 | -0.125 |
| t = 5 | $p^1$ = 1, 1, 1, 1, .75<br>$E(p^2)$ = 1, 1, 1, 1, 1 | .5 + .5 + .5 + .5 + .75 = 2.75 | +0.25 |

Assumes zero discount rate.

As shown in Table 3, the potential gains from defection in any period do not outweigh the anticipated losses in future profits until the last (t = 5) period. At that point, supplier 1 in this illustration, believing that its competitor will continue to match the monopolistic price they have both adhered to in the previous periods, may be tempted to undercut in the last period since there is no potential future gain to be had from signaling on intent to maintain the monopoly price. So in this last period, continuation of the myopic view of the competitor's likely price behavior that is described in Table 3, while consistent with actual behavior up through t=4 and therefore a rational expectation, leads to a price undercut in the final period.

Of course, if endowed with a bit more foresight, it can be shown that firm 1 might expect its symmetrically situated competitor to come to the same conclusion that it does in the final period and to also be tempted to undercut. In that case firm 1 would conclude that by undercutting it would actually receive a profit of at most .375 in the last period if firm 2 were to reach the same conclusion. Now each firm faces a dilemma: they may be able to earn a fifth year profit of .5 if they both retain p = 1, but then they run the risk of earning nothing if the other firm defects, or of earning $\pi$ = .375 if they defect and the other firm holds to p = 1. The key is that with no future period's profits tied to the current period's pricing behavior, in the last period both firms are thrown into the traditional single-shot game, and the likely behavior is similar to that in Table 2. In the last period, both firms will fall into the prisoner's dilemma of undercutting, and in doing so they will likely reach a Nash equilibrium of $p_5^1 = p_5^2$ = .25, since this set of prices also represents a min-max solution; whereas by setting $p_5^1$ = .5 firm two might be anticipated to do just as well by undercutting to $p_5^2$ = .25, which however leaves firm 1 with zero profits.

This discussion focuses the debate inherent in the traditional literature on repeated , non-cooperative games (See Friedman, 1997 and 1985, [6], [7], Fudenberg and Levine, 1983 [8] and Benoit and Krishna, 1985 [9] as examples) which leads to competitive behavior and Nash equilibria, as compared to the application of the benefit-denial principle which leads to implicit, self-interest-motivated collusion. If there is a finite time horizon, the operation of the consistent expectations developed under one competitor's observations of responses to its own previous price behavior and of mapping out its strategy accordingly, collapses in the last period. At that point, traditional non-cooperative supergame literature would seem to take over, since if the best any supplier can do in the last period is to undercut prices down to the Nash equilibrium level, then the optimal solution to this dynamic optimization problem over a finite time horizon is to work backward, one period at a time, to the present. In this two player example, if the best solution in t = 5 is $p_5 = .25$ with $E(\pi_5) = .125$, then the best play in t = 4, knowing with certainty the last period's outcome, is to also offer $p_4 = .25$, and so on recursively to the present until we find the five period Nash equilibrium price vector for each supplier is p = (.25, .25, .25, .25, .25). In game-theoretic language, this solution to the dynamic programming problem is sub-game perfect, since it describes each player's best strategy in each time period looking to the future, regardless of what has happened before.

What causes the strategies developed carefully under the benefit denial principle to unravel is the competitive nature of the best strategy for the final period when there is no tomorrow. But in actual application, this should not be a debate over infinite versus finite games; rather the outcome hinges on whether in the final period of a repeated game of finite duration, each player sees their final price offer affecting their total net present value through some mechanism other than their last period's profits. If, as an example, as a consequence of the price offered in the last period, the value of some future asset is also affected, as well as the last period's profit, the firm may still determine, based upon the benefit-denial principle, that it is in their own best interest to offer the monopoly price in the last period. As an example, if following the last period's market allocation, each firm is offered the future asset value of the firm and that future asset value is thought to be determined by anticipated future market-clearing prices that are determined by the past history of price behavior, including prices in the last period, then by the logic employed in developing the strategies in Table 3 that sustains the monopoly price over first four periods, a residual future asset value greater than .25 is all that's required to induce the suppliers to maintain the monopoly price in the last period. Since that asset value should be approximated by the net present value of a subsequent cash flow stream out to infinity, the finite game can be viewed merely as a truncated version of the infinite game, and so long as the terminal asset value hinges on the prices charged in each previous period, then even in the final period of the finite game, the benefit denial principle should induce the players to maintain their offers at p = 1 in the final period.

In this example of Table 3, even if a real discount rate of ten percent applied beyond period five, the terminal asset value based on expectations of continued prices at the monopoly level equal ($s^i p^i/r$), where r = the discount rate, so the terminal value would be (.5x1/.1) = 5.0. If, however, price undercutting emerges in period five, the asset value drops to (.5 x .25/.1) = 1.25, a loss of 3.75 which is much greater than the loss of .25 necessary to sustain a monopoly price in the last period. Even if both firms are myopic enough to expect an undercut price of .75 in the last period to be sustainable to infinity in the future, the terminal asset value would be (.5 x .75/.1) = 3.75, which represents a loss of 1.25 over sustaining the monopoly price. Since any loss in terminal value greater than .25 is sufficient to induce both suppliers to set p = 1 in the fifth period, they should maintain monopoly level prices throughout.

What has not yet been demonstrated is if the two firms begin the five period game by charging some price below the monopoly level, whether or not through the benefit-denial principle they would be induced to raise their offers to p = 1. As show in Table 4; however, even if both firms begin the series of auctions charging the one-shot Nash equilibrium price = .25, under the conjectures developed in Table 3, it is worth the trial of raising the offers to the monopolistic level in order to verify the behavior of the competitor.

Table 4. Illustration of Benefit Denial Principle Starting with Competitive Prices

Case (i) - Continued Undercutting

$p^1 = p^2 = .25, .25, .25, .25, .25; \pi^1 = \pi^2 = .625$

Case (ii)- Firm 1 applies benefit denial principle under conjectures of Table 3.

$p^1 = .25, 1, 1, 1, 1$ $\quad\quad E(p^2) = .25, .25, 1, 1, 1$

$\therefore E(\pi^1) = .125 + 0 + .5 + .5 + .5 = 1.625$

Discount Rate = 0

As shown in Table 4, even without the benefit of a massive terminal asset value, it pays each firm to try lifting its price to the monopoly level, even though each expects to lose all sales in the initial period of price increase. In fact, in this example, even if it takes three periods of charging monopoly prices to induce the competitor to raise its price, firm 1 can expect to be no worse off than they were under the mutually competitive scenario.

The conclusion of this conceptual analysis of repeated games, therefore, is that offers into fixed-demand auctions are likely to reach monopolistic levels over time, even when there is substantial excess supply capacity. The variable that hasn't been included, analytically, is the cost impact of applying these computational principles as the number of suppliers increases. Both to explore the effect of the number of suppliers, and also to verify the conceptual analysis provided thus far, experimental results are summarized next.

## 3. Verification Through Market-Simulation Experiments

In auction experiments reported by Bernard, et. al., 1998 [4], the competitiveness of market-clearing prices was shown to be inversely related to the number of generating firms bidding into any single market. Where only two suppliers bid into a market, prices rapidly rose until reaching a plateau of a level approximately twice marginal cost, although approximately twenty percent below the pure monopoly level. With four suppliers, prices generally fell toward the competitive level after the first few repeated auctions, but after thirty to forty trials with the same players competing, prices begin to drift up again reaching a level approximately thirty percent above marginal cost after 75 repeated trials. With six competitors in these experiments, prices were quickly driven to within ten percent of marginal cost, where in most cases they remained for the rest of the trials. In several instances, however, there were some signs of prices beginning to drift up after 60 repeated trials, and so future experiments with more than 75 repeated trials may be warranted to see if this many players can and are willing to signal each other in order to attempt to raise their prices and earn greater profits.

In each of these experiments, three different market-clearing price determinations were tried: price equals last accepted offer (LAO), price equals first rejected offer (FRO), and the multiple unit vickery (MUV) auction clearing prices (see Vickery, 1961, [10]). While the MUV auction proved to be more efficient in selecting generators with the lowest costs for auctions with both two and six participants, and it led to slightly lower marginal prices for auctions with six bidders, it also generally yielded higher profits for the suppliers overall, because their revenues are derived from a form of price discrimination. Overall, the LAO auction did almost as well, leading to lower prices in markets of two or four suppliers than did either the FRO and MUV auctions, and so subsequent experimental results described are for LAO auctions because they are simple to explain and implement.

In all of the experiments described, twenty-four participants were present in the room simultaneously where they each made their offers into their own computer terminals. Each supplier had three different blocks of generating capacity with three different marginal costs. They were told what the market demand was, how many competitors each faced and that their competitors had supply characteristics that were approximately the same as their own; however, they did not know the identity of their competitors so they could not give voice or hand signals across the room. After each auction period, each supplier learned the market-clearing price and how much he/she had sold of each type of generating capacity. The participants were paid what they earned in the auction plus an additional $5.00 for participating.

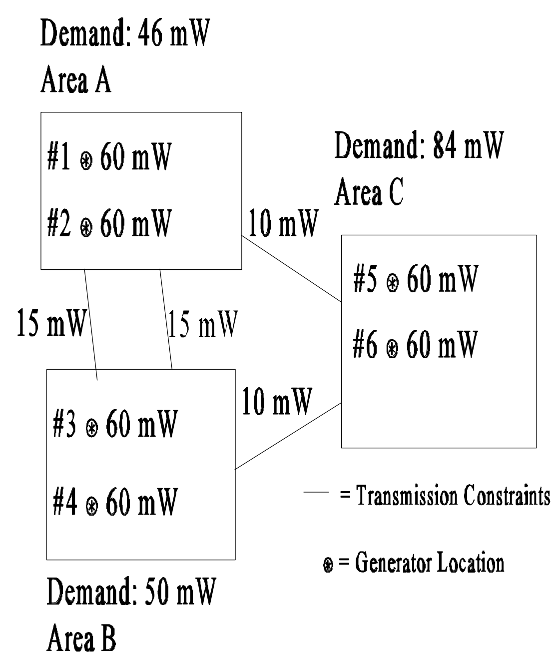


Figure 1. Schematic Diagram of Electrical System Used to Clear Market Experiments: Three Load Areas, 24 Demand Buses, Six Competitive Generators

Having established a baseline of auctions results where the market is cleared without any physical constraints due to infeasible power flows, the auction experiments were repeated where the market was cleared through a simulated twenty-four demand bus power grid with six separate generators supplying the power. In this case, each of the six auction participants representing one of the generators was shown the schematic diagram of the electrical system in Figure 1 before the repeated auctions began. Furthermore, as in the auctions into a single node, each supplier had three increments of power at different marginal costs adding to a total of 60 mW of capacity, and they were told that their competitors had similar supply characteristics. Following the submission of offers, the market was cleared using an optimum power flow (OPF) procedure that attempts to meet all demands at minimum total cost, subject to the transmission line capacity constraints show in Figure 1, plus meeting minimum voltage constraints on lines connected to each of the 24 demand busses.

## Description of Smart Market

These experiments used a LAO auction with prices and offers adjusted for location in the network via an OPF (optimum power flow). This "smart" market is needed to account for the operational constraints imposed by the physical transmission network. In this context, the sellers and the buyer's demands are connected by a transmission network which must be operated at all times in a manner consistent with the laws of physics governing the flow of electricity. The operation of the network is also constrained by the physical limitations of the equipment used to generate and transmit the power. This results in two phenomena which may affect the auction: (1) transmission losses and (2) congestion.

A small percentage of the energy produced by the generators is dissipated by the transmission lines. The amount of power lost depends on the flow in the line and the length of the line, among other things. Transmission loss implies that the total amount of power the buyer must purchase is slightly greater than the total demand and the exact amount is dependent on where the power is produced.

There are limits on the amount of electric power that can be transmitted from any given location to any other location. Some of the limits are simple line capacity limits and others are more subtle system constraints arising from voltage or stability limits. Congestion occurs when one or more of these network limits is reached. Congestion implies that some inexpensive generation may be unusable due to its location, making it necessary to utilize a more expensive unit in different location.

The effects of losses and transmission system constraints are handled by adjusting all offers and prices by a location specific transmission charge which represents the cost of transporting the electricity from the respective generating station to some arbitrary reference location. There is a two part transmission charge associated with each line which is divided up between the various generators based on their individual contributions to the flow in the line. The per-line transmission charges can be explained as follows. The value of the power dissipated by a transmission line is the loss component of the transmission charge for that line. The congestion component of the transmission charge is precisely the charge necessary to discourage overuse of the line. If there is no congestion, this component is zero. It is important to note that the transmission charges are dependent on the flow in each transmission line as well as each generator's contribution to that flow and therefore cannot be computed before performing the auction. In this context, each generator receives a price which is specific to its location.

Units are chosen so as to satisfy the demand in the least expensive manner while satisfying the operational constraints of the transmission system. This is done by an optimal power flow program which computes the appropriate transmission charges for each generating station. The units selected by the optimization program are roughly those given by the following procedure. The appropriate transmission charge is added to the price of each offer, and the offers are ordered from the lowest to highest adjusted offer price. Units are included for sale, starting from the low priced units and moving toward the higher priced units, until the supply reaches the total buyer's demand plus transmission losses. The remaining, higher priced, units are excluded from sale.

The reigning price is set to the adjusted offer price of the last (most expensive) unit chosen. The price paid for each unit produced by a given generator is the reigning price minus the corresponding transmission charge.

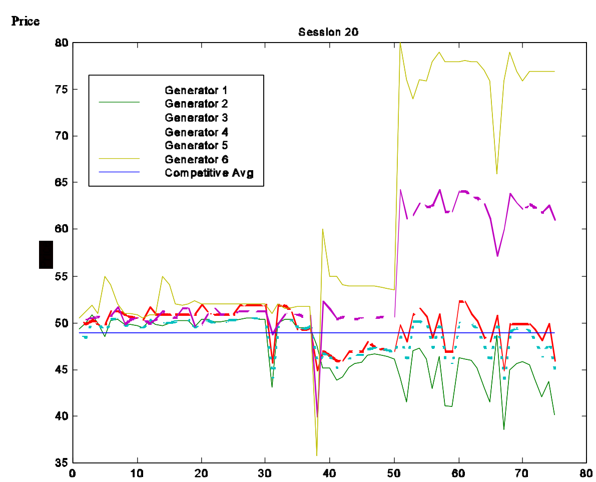


Figure 2. Illustration of Market Clearing Prices in Experiments with Electric Power System Constraints

### Auction Results

A major objective of these experiments was to determine if undergraduate students who were not experts on power system operational characteristics could determine, through trial and error experiments, that they were effectively in a duopoly market situation (generators 5 and 6) and to what extent they would exploit those offers by raising prices well above competitive levels. The results shown in Figure 2 are typical and demonstrate how after several attempts at raising prices generator 6 is finally able to entice generator 5 to follow suit after nearly forty trials, and thereafter they exploit their monopoly power in the load pocket they are serving. Meanwhile, the prices offered by the four other generators who serve a more accessible market configuration oscillate around the competitive price.

In other market iterations with different participants, several groups never exploited the load pocket situation; whereas, other groups had generators 5 and 6 offering close to the monopoly price form the outset. The point is, if many untrained undergraduates can quickly identify and exploit opportunities to exert market power, similar results are to be expected in actual bulk power auctions. Furthermore, during peak load periods in many areas of the country where total available capacity is less than the 360 mW in these experiments that is available to meet a 180 mW demand (100 percent reserve margin) the exercise of market power might be expected to be far more pronounced. This is one set of circumstances that will be explored in future experiments.

## 4. Additional Opportunities for Market Power through Retail Wheeling

Assuming that the electric transmission system, the source of the remaining natural monopoly power in the electricity supply system, will be operated under the guidance of an independent system operator (ISO) in the public interest; nevertheless, individual power "assemblers" who buy electricity from the exchange and offer to sell it to retail customers after adding transmission and distribution "wire" charges may be able to exert additional market power. This opportunity arises because of the observed lagged response by many retail customer to emerging lower priced opportunities. As explained in detail by Schuler, 1998, [11], realistic estimates of these delays in the rate at which customers take advantage of lower-priced opportunities affords suppliers, particularly those in dominant market positions, the opportunity of engaging in monopolistic pricing practices, recognizing that their customer base will erode only slowly over time.

Particularly for those suppliers with initial market shares in excess of 70 percent and where a speed of response parameter, roughly related to the percentage loss in market share, per year caused by a one percent price disadvantage with respect to competitors, is less than one, the firm with the dominant market share should find it in its profit-maximizing interest to charge a price close to the monopoly level despite much lower prices offered by it competitors. The rate at which market share is eroded is just not fast enough to offset the large near-term profits reaped from those customers who remain "loyal".

Furthermore, as demonstrated in the earlier work by Schuler, 1998, [11] the theoretical derivation of these results does not require reliance upon the benefit-denial principle; simple myopic greed is sufficient. Here, the link between time periods that forestalls the onset of intense competition is not due to the firm's expectations about how their price behavior will influence the way other firms will set prices in the future. Rather, it is based upon the observed market adjustment friction that means even if a firm charges a higher price than its competitor, that while it will lose some market share in the next period, all is not lost instantaneously. Thus between each of two periods, each firm is faced with a tradeoff: to charge a higher price in the current period and earn greater current profits, but then to lose market share in the next period. Here, a myopic, multi-period profit maximizing calculation results in the persistent exercise of monopoly power, particularly by the firm with a substantial initial market share, and the resulting Nash equilibria solutions leave the dominant firm charging near-monopoly level prices over much of the finite time horizon. Here the solutions satisfy the backward recursion optimality conditions, period by period, of a sub-game perfect equilibrium.

The results of an example calculation for a five period game where all prices are normalized by the difference between the monopoly price and marginal cost ($0 \leq p \leq 1$, where $p = 0$ is marginal cost and $p = 1$ is the monopoly price) are summarized in Table 5. Here the real discount rate is set at three percent (the results are quite insensitive to variations in the discount rate) and equilibria pricing strategies are computed for a variety of assumptions about initial market shares and the speeds of market share adjustment. As shown in Table 5, the most highly competitive price behavior emerges when both suppliers in this duopoly calculation begin with equal market shares. Nevertheless, the ability and willingness to exercise market power also hinges to a large extent on the speed of customer response ($\lambda$). For $\lambda = .25$, a value similar to the experience when competitive long distance telephone calling was introduced initially in the United states, even with equal initial market shares, the suppliers are expected to price in a way that extracts nearly 98 percent of maximum obtainable profits. It is only where that adjustment speed is four times as fast that profits begin to fall. Still, at $\lambda = 1.0$ but with the dominant firm holding 90 percent of the market at the outset, that firm is never induced to match its competitor's low, marginal-cost-based prices throughout the five periods, even though its market share falls to 63 percent by the end of the fifth period.

## 5. Implications for a Deregulated Industry

The opportunities to exercise market power in deregulated electricity markets that are described above may lead to prices for the generation portion of electric bills that are well above marginal cost in many locations around the country. While the exercise of that market power is likely to generate political reverberations, in fact profits that exceed average rates of return for comparable industries also have a tremendous salutory effect; they can be the grease that speeds entry and technological change. Thus substantial profits in the short run can lead to lower prices in the long run if the electricity supply industry is responsive, technologically and economically. To the extent that the market power is prolonged by government enforced regulatory and institutional constraints, the subsequent benefits may be harder to achieve, so the first step is to minimize the extent of administrative constraints in the process of deregulation.

The analytic portion of this paper demonstrated two underlying sources of market power. The first was constraints on the ability to transport electricity from low cost suppliers to markets served by generation with higher costs because of limited transmission capacity. This problem can be compounded by complex operating rules and regulations invoked in the name of maintaining system reliability. The net result was shown to be market-clearing prices at the power exchange that might exceed twice marginal cost. The second source of market power is self-inflicted by consumers who respond slowly to lower-price supply options in newly deregulated markets. In this case marketing agents who buy power off the exchange and sell a commodity package to retail customers may be able to raise their price appreciably above marginal cost for prolonged periods before their market share is significantly eroded.

Together, however, these two sources of market power would not be multiplicative or additive; instead they would be substitutes since they compete with each other for the same additional consumers' dollars. Electricity supply costs are comprised of three components: generation, transportation (transmission and distribution) and administrative expense (marketing, billing, credit, etc.). Both the generators selling into the bulk power exchange and the retail marketing groups who buy power off the exchange and sell to customers are in the market supply chain for the same commodity portion of the business. Thus, to the extent that the generators are able to extract full monopoly rents through their offers into the exchanges, there are no more additional profits to be reaped by the marketing firms from additional price hikes for the same commodity. Conversely, if the generators are unable to exercise market power, retail marketing agents may be able to gain substantial monopoly rents, but they both can't capture the same profit. Regulatory bodies can reduce the possibility of this second source of market power both by disseminating information widely and clearly about the choices becoming available, and by requiring a market structure where no single retail supplier has more than half of the market and where there are more than four reliable suppliers.

Note, also that where under the negotiated process of deregulation, the utilities are allowed to recover their "stranded costs" (costs incurred for equipment or service contracts that are not competitive in a market environment) through wires charges added to each kWh sold, those charges will act like sales taxes and reduce the monopoly rents that would have been earned through the exercise of market power. Again, stranded costs recovered through a per kWh charge will substitute for, not add onto, price rises that might be induced by the exercise of market power. So in total with generation cost averaging $.045 per kWh and the wires and administrative component adding another $.045 per kWh, a market-power doubling of generation costs would raise customer prices to $.135 per kWh, a 50 percent increase.

The important question that remains is if new transmission capacity can be provided by augmenting the existing system, altering operating procedures or building new lines, or whether the construction of additional nearby generating capacity will be the quickest response to these profit opportunities. If additional power flows could be squeezed out of existing lines (or if rules and regulations currently inhibit efficient transfers), solving those problems should receive the highest priority. Here, however, institutional and regulatory rules may inhibit progress, particularly if the traditional utilities remain vertically integrated, and they continue to exercise a voice on power pool operating rules that might indirectly influence the economical dispatch of power that could reduce market power, of which they are the beneficiaries. Generation must be separated institutionally from transmission and distribution if these risks are to be minimized. Furthermore, the independent system operator (ISO) that is being developed in many regions to insure the operating integrity of the transmission system, is also being assigned the responsibility for overseeing the power exchange (as in New England); whereas, these two functions are being kept separate elsewhere (e.g. California).

In fact these two functions, efficient power

exchange and maintaining reliability, intersect in many ways, and it is a
debatable question of organization theory which institutional structure will perform this coordination problem most effectively. Does internal debate under a single institutional umbrella, versus two seperate entities each pursuing their own objectives, subject to transparent incentives that are imposed to reward each other for weighing reliability versus economy considerations, lead to the best results? We simply don't know, but if the proper institutional incentives and mechanisms are not in place to provide additional transmission capacity, we can be sure that attempts to complete new combined cycle gas turbine facilities will be the consequence of persistent market power. Furthermore, since the time to completion of these facilities is usually less than three years, unless siting problems are incurred, then any exercise of market power should not be too prolonged.

Furthermore, even smaller scale technologies like fuel cells and micro turbines are waiting in the wings, and their implementation, probably at the distribution level, would be greatly accelerated by any prolonged exercise of market power (see Lasseter, 1998, [12]). So short run profits earned by suppliers in deregulated power markets should put in place an interesting race. Either the regulators, together with the ISO and utilities can agree to rules, practices and incentives that unblock transmission bottlenecks and subsequently reduce market power, or powerful incentives will exist to build even more generation and to evolve an electricity supply system that is primarily comprised of distributed generation. Will rules and regulations that were put in place to support the traditional system guarantee that the alternative small-scale distributed system wins?

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**Table 5-Nash Equilibria Pricing Strategies and Profits in a Five Period Dynamic Game with Two Competitors, (p∈[0, .25, .5, .75, 1], r=.03)**

| **Market Adjustment Speed, λ** | **.25** | | | **.5** | | | **1.0** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Competitor's Initial Share $S_1^2$** | .1 | .3 | .5 | .1 | .3 | .5 | .1 | .3 | .5 |
| **<u>Competitor's Behavior</u>:** | | | | | | | | | |
| **Price = $p^2$** | [.5,.75,.75 ,1, 1] | [3-.75's, 2-1's] | [2-.75's, 3-1's] | [0,.5,.5, .75,1] | [.5,.5,.75, .75,1] | [.5,.75,.75,1 ,1] | [0,0,.25, .75,1 | [0,.25,.5,.75,1] | [.25,.25,.5, .75,1] |
| **Share = $S^2$** | [.1 → .12] | [.3 → .33] | [.5 → .5] | [.1 → .23] | [.3 → .38] | [.5 → .5] | [.1 → .37] | [.3 → .47] | [.5 → .5] |
| **NPV Profits = $^{2}$** | .50 | 1.42 | 2.30 | .62 | 1.42 | 2.17 | .76 | 1.31 | 1.66 |
| **<u>Dominant Firm's Behavior</u>:** | | | | | | | | | |
| **Price = $p^1$** | [5-1's] | [.75,4-1's] | [2-.75's, 3-1's] | [5-1's] | [3-.75's, 2-1's] | [.5,.75,.75,1 ,1] | [4-.75's, 1] | [3-.5's,.75,1] | [.25,.25,.5, .75,1] |
| **Share = $S^1$** | [.9 → .88] | [.7 → .67] | [.5 → .5] | [.9 → .77] | [.7 → .62] | [.5 → .5] | [.9 → .63] | [.7 → .53] | [.5 → .5] |
| **NPV Profits = $^{1}$** | 4.17 | 3.20 | 2.30 | 3.91 | 2.98 | 2.17 | 3.34 | 2.27 | 1.66 |
| | ------------ | ------------ | ------------ | ------------ | ------------ | ------------ | ------------ | ------------ | ------------ |
| **Combined Profit** | 4.67 | 4.62 | 4.60 | 4.53 | 4.40 | 4.34 | 4.10 | 3.58 | 3.32 |
| **Percent of Maximum Profit (4.72)** | 98.9% | 97.9% | 97.5% | 96.0% | 93.2% | 91.9% | 86.9% | 75.8% | 70.3% |