A Cournot-Nash Equilibrium
Analysis of the New Jersey Electricity Market

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Executive Summary

This report describes the results of a preliminary study that was performed in order to analyze the potential for market power in a restructured electricity industry in New Jersey. Our primary focus in this study has been on the New Jersey market, rather than the broader PJM market. Limitations on transmission capacity, both outside of and within the PJM control area, imply that New Jersey may at times constitute a market that is geographically distinct from the rest of the PJM pool. One of the purposes of this study is to assess both the impact of such congestion and the amount of time that congestion is likely to be a problem.

The focus on New Jersey comes at the expense of some insights into the broader PJM market. We have assumed that the western portion of the PJM market will be perfectly competitive at all times. We therefore assumed that all generation resources in this area, including those owned by firms with resources in New Jersey, would operate whenever prices were above operating costs. We also assume that there is enough generation capacity in eastern New York to always provide exports into the New Jersey up to the limitations of the transmission lines. If capacity is instead limited in these regions by the need to serve native loads or by the existence of market power in those states, our results would understate the potential for market power in New Jersey.

The approach used in this study is to calculate an economic equilibrium concept known as the *Cournot-Nash* equilibrium. In a Cournot-Nash equilibrium, each firm considers the output of all the other firms and sets its own output in a way that maximizes its profits when selling to a price-responsive demand curve. In equilibrium, each firm is producing at its profit-maximizing output, given the output of all the other firms. This is an approach we have applied in detail to the electricity market in California and the western U.S. [2]

While a Cournot analysis allows us to examine a broader range of potential strategic actions than do concentration measures, it is important to keep in mind that it is still a very stylized representation of both the costs and range of strategies available to firms. The results should therefore be thought of as a screening for the potential for market power, and a characterization of some ways such potential might manifest itself, rather than a forecast or prediction of market prices.

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[2] Borenstein, Bushnell, Kahn, and Stoft (1995), Borenstein, Bushnell, and Stoft (1997), and Borenstein and Bushnell (1997). These papers are available for download from the Energy Institute website at http://www-ucenergy.eecs.berkeley.edu/ucenergy.

We calculate the Cournot-Nash equilibrium for a series of demand levels ranging from current off-peak levels to the forecast peaks for 2010. We model a price responsive demand curve that passes through these demand levels at current prices. The equilibria result in very little price mark-up over cost for PJM-East demand levels below 14,000 MW. At levels higher than that, there can exist equilibria where the price mark-up grows rapidly with demand. We argue that the sensitivity of these results to other factors outside of this analysis, such as reserve margins and the addition of new transmission or generation capacity can be roughly approximated by adjusting the level of demand.

These findings should not be seen as suggesting that deregulation and competitive restructuring are mistakes. Very few markets are completely devoid of market power. One must compare the prices consumers will face in a deregulated market with the outcome under the current regime or some other baseline. While the techniques we employ here could be used to address some of these questions, it would require a more detailed analysis of this market than we have thus far carried out.

1.0 Market Power Analysis

The first step in analyzing the potential for market power in an industry is to define the markets that are of interest. In the electricity industry, this can include markets for contractual agreements, such as contracts for differences or physical bilateral contracts, and markets for ancillary services, such as spinning reserve and voltage support, in addition to the central product of electrical energy. In this report, we discuss only issues relating to the *energy* market. We also address only the issue of *horizontal* market power, that is, the market power associated with the concentrated ownership of production resources. In doing so, we have assumed that transmission access will be provided in an efficient, non-discriminatory manner, thereby eliminating *vertical* market power issues.

One of the fundamental market power measurements is the price-cost margin.[3] That is to say, we are often concerned that prices might be significantly above marginal costs. Such pricing leads to inefficient allocations, since consumption will be too low as prices are too high, and possibly to inequitable transfers from consumers to producers. In most industries, analysts are unable to measure price-cost margins, since costs are usually the private information of the producers. Often concentration measures, such as the Hirschmann-Herfindahl Index (HHI) are used instead. Measures of industry concentration and individual firm market share are often correlated with market power, but this is not always the case.

Some of the weaknesses of concentration measures as indicators of market power are exacerbated when applied to the electricity industry. Market definitions, which are always an issue in the use of concentration and market share measures, in electricity markets will depend on transmission constraints, which will vary with load, and may be determined by firms that also own generation and distribution assets. Within a market, firms will have differing incentives to try to raise or lower the wholesale price, which will depend on the degree of vertical integration and the ability to hedge price risk in the market. Though standard measures of concentration provide some information about the potential for market power abuse, it is clear that they cannot capture some of the most important information necessary for the analysis.

Even within the generation market itself, the standard structural measures suffer two serious shortcomings in the context of electricity markets. First, traditional “market share” measures, based upon historical sales, are of questionable value since the nature of the market after deregulation will be so radically changed. Second, other structural measures that don't rely on historic sales, such as generating capacity, do not account for the relationship between capacity and demand or the relative cost curves of competitors (these features would, to some extent, be reflected in measures based upon historical sales, if those were relevant for the restructured industry). In particular, capacity-based measures do not incorporate the extent to which independent generating capacity and

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[3] The price-cost margin, often referred to as the Lerner index, is defined as $\frac{P - MC}{P}$.

imports can meet demand and whether the marginal cost of that capacity is competitive with that of dominant firms.

The most widely used structural measure of concentration in a market is the Hirschmann-Herfindahl Index (HHI), which is defined as the sum of the squared market shares. An appeal of the HHI is that it is linked directly to market power in one theoretical model of competition, known as *Cournot* competition (See Tirole, 1988). Two factors, in general, determine the level of market power that a firm can exercise: the elasticity of demand in a market and the degree of competition among sellers. In perfect competition, the elasticity of demand becomes irrelevant due to the intensity of competition. In monopoly, only the demand elasticity matters since there are no competitors. In *symmetric* Cournot competition, in which all firms have identical cost functions, the price-cost margin will be:

$$\frac{(p - MC)}{p} = \frac{1}{n} \cdot \frac{1}{\varepsilon} = \frac{HHI}{\varepsilon} \qquad \textbf{(1)}$$

where ε is the elasticity of market demand and n is the number of identical firms. Thus, the HHI measures directly one of the two factors that determine the exercise of market power, but it gives no indication of the elasticity of demand and, therefore, very imperfect indication of the severity of the market power problem. In this case, the HHI indicates by how much price exceeds marginal cost relative to the outcome that would result under monopoly. Predicting oligopolistic equilibria can be difficult and often requires a great deal of proprietary data, while computing an HHI is often fairly straightforward. However, in the electricity industry, with its long history of regulation, there is a wealth of cost information available. This allows us to simulate the price cost margin directly.

1.1 Cournot Equilibrium Concept

The cornerstone of our analysis is the assumption that strategic players employ *quantity strategies*. That is to say that each strategic player, upon observing the output of its competitors, would select a production quantity that would maximize its profits. In an equilibrium, every producer has an output that maximizes its profits, given the output of every other producer. Therefore, no producer would find it profitable to unilaterally change its output. This is known as a *Cournot-Nash Equilibrium*.

Unlike the concentration measures discussed above, an equilibrium analysis such as this one can be used to investigate what happens to prices when one firm reduces its output. This is a critical question in the electricity industry where the product is, with some exceptions, not storable and short-run demand is relatively inelasitic. Even though one firm may have an apparently small market share at a given demand level, it may be the case that if that firm reduced output, no other firm may be able to replace that supply because of capacity or transmission constraints. The Cournot-Nash algorithm described below helps to analyze and detect such situations.

In the context of an electricity market, the Cournot model seems an appropriate starting point. The other basic non-cooperative equilibrium concept, the Bertrand equilibrium, is supported by the assumption that any firm can capture the entire market by pricing below others and can expand output to meet such demand. Since generation capacities present significant constraints in electricity markets, this assumption is not tenable. Previous research suggests that if firms choose their capacities and then compete on price, within the restrictions of their capacity constraints, the outcome may be closely approximated by the Cournot model.[4]

Capacity constraints on generation are significant in both the medium-term – based upon investments in construction of new capacity – and the short-term, in which plants are rendered "unavailable" due to maintenance and other reliability considerations. This latter, short-term, constraint is most relevant to this study, since the capacity investments of the major players have already taken place.[5] In their study of the UK electricity market, Wolak and Patrick (1996) argue that the market power of the dominant firms is manifested through those firms declaring certain plants unavailable to supply in certain periods. Thus, the centralized price mechanism and capacity-constrained suppliers in electricity markets (at least during peak periods) support the use of a Cournot model for a base case analysis.

Another game-theoretic concept that has been applied to electricity markets is the modeling of equilibria when bidders specify full cost-quantity 'supply-curves.'[6] However, this approach does not lend itself well to markets where there is a competitive fringe whose capacity may be limited due to either generation or transmission constraints.[7] Since this is a central question that we wish to examine in the context of the PJM-East market, this approach does not appear to be appropriate.

While one could model the industry as either perfectly competitive or perfectly collusive, these extreme models are poor representations of the market. Firms may be able to reduce rivalry through repeated interaction, as we discuss below, but antitrust laws and the natural tendency to cheat on collusive agreements make a *perfectly* collusive view of the electricity market hard to credit. Furthermore, modeling the non-economic factors that might support explicit collusion – such as common background, threats to individuals, or technology for monitoring and enforcing such collusion – is beyond the scope of this study and the authors' expertise. At the opposite extreme, while firms may compete fairly aggressively at times, there are at least a few firms in New Jersey that could, in peak demand hours, potentially profitably raise price by restricting output. Thus, a perfectly competitive model of this market, in which no firm recognizes the effect of its marginal production on the price it receives for all of its output, is simply not

[4] See Kreps and Sheinkman (1983). See Davidson and Deneckere (1986) for discussion of the limits of this finding.
[5] There is one other significant short-term capacity constraint, involving the commitment of generation units to a dispatch process. Since most generation units are constrained on how quickly they can begin producing output from a shut down state and how quickly they can increase output to higher levels, generators must commit to certain output capabilities before they actual provide output in a given hour. We discuss the qualitative implications of these constraints on our market power model later in this paper.
[6] See Green and Newbery (1992) for examples of this approach.
[7] This is due in part to the fact that, to date, supply curve models have relied upon the assumption that the elasticity of demand does not vary across time periods (or demand levels).

tenable. Furthermore, it is not possible to analyze the potential for exercise of market power using a model that by assumption does not permit the exercise of market power.

1.3 Limitations of Static Equilibrium Analysis

None of the models that we have discussed thus far incorporates some potentially important dynamic aspects of competition. First, interactions among firms in a market take place repeatedly over time. In a dynamic model of repeated interaction, it is possible that firms will learn over time to compete less aggressively with one another. Also, repeated interaction allows a firm to more credibly threaten to punish a rival who behaves non-cooperatively. Faced with a more credible threat of retaliation, a firm is less likely to compete aggressively. Reduced rivalry between firms would lead to higher prices and lost consumer welfare.

Closely related to the repeated interaction considerations is the issue of sales that take place through forward or futures contracts.[8] Such futures markets allow a seller to precommit to output, thus ensuring it a certain quantity of sales. Even for sales of electricity for delivery at a certain point in time, repeated interactions among firms in selling that product – through many days of advanced sales of the good – can have complex effects on the nature of competition. Theoretical work in economics has shown that such repeated interaction can increase or decrease the level of competition between incumbent firms.[9]

A dynamic model of competition, however, would also take into account the effect of actual or potential new entry into the market and possible exit from the market. The possibility of new entry might prove to have a significant disciplining effect on prices and might offset any increased cooperation among incumbent firms in a dynamic setting. If prices over the year are too low to cover a plant's fixed operations and management costs, the plant might shut down, lessening the number of plants and the intensity of competition.

Unfortunately, economic models of dynamic competition in general do not provide a clear guide to either appropriate empirical modeling or the net effect that these factors are likely to have on prices. Furthermore, the models often yield indeterminate results, such as any price between the perfectly competitive outcome and the perfect collusion outcome being a possible equilibrium. Empirical analysis of the dynamic nature of competition among a fixed set of competitors also is notoriously difficult.[10]

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[8] We use the term futures market to refer to trades that are contracted for prior to delivery. Whether these take place in formal futures markets – which have standardized contracts and a centralized trading system – or less formal forward markets – in which contracts are not standardized – makes no difference to the argument. Also, whether most such contracts actually result in product deliveries or are settled financially is irrelevant so long as the contract represents an option for physical delivery.

[9] See Allez and Vila (1993) for an example of the former. and Ausubel and Deneckere (1987) and Gul (1987) for examples of the latter.

[10] There have been a few attempts to analyze dynamic competition and cooperation (Porter (1983), Ellison (1994), Borenstein and Shepard (1996)), but they have focused on testing very specific aspects of the dynamic models. We are not aware of any work that has applied models of dynamic competition to infer the extent of market power that will be exercised in a market.

2.0 The New Jersey Electricity Market

Utilizing production cost and capacity data provided to us by Haglar-Bailly, and taking into consideration the factors described in the previous section, we have simulated the New Jersey electricity market to find Cournot-Nash equilibria under varying parameter values. To keep the complexity of the model within acceptable limits, we divide electricity producers into two categories, strategic firms (those with enough capacity to potentially exercise some market power), and non-strategic, "fringe" firms (those with little or no market power). Other key modeling assumptions are described in the following subsections.

2.1 Regional Market Definitions

Utilities outside of New Jersey are grouped into Western and New York markets. These groupings along with the transmission capacity from these regions into New Jersey are shown in table 1. Since our focus is on the potential for market power in New Jersey, and the market in the western portion of the PJM pool appears to be relatively competitive, we have assumed that firms located in our "western" region will have little market power and will therefore act non-strategically.

Several firms own generation capacity on both-sides of the PJM east demarcation. This adds complexities to the incentives of these producers. When transmission into the New Jersey area is congested, this western generation capacity would earn the western spot price (which would differ from the spot price in New Jersey), and therefore would not be viewed as inframarginal by those firms when they find the profit maximizing output for their capacity in New Jersey. That is, New Jersey firms would recognize that restricting output in the state would not raise the price they would receive for power produced in the western region. Therefore, in this analysis, we treat this western capacity of these firms as price-taking fringe capacity and the Cournot calculations include only the generation capacity owned by those firms in the PJM-East area. This may understate the potential for market power in hours in which the PJM-East path is not congested. At some extremely high demand levels, this path was not congested due to the fact that PJM-West generation was needed to serve western load. Cournot prices tended to be extremely high during these periods anyway, even with the assumption that western generation resources were operated competitively.

The ownership of transmission rights can also affect the incentives of the firms. If a firm located in the PJM-East region owns a transmission contract that entitles it to the difference in the spot prices in the western and eastern regions, then the revenues associated with this contract should be added to its profit calculations. If a firm has a 1000 MW contract of this form, this is equivalent to having a 1000 MW must-run plant that would be included in the inframarginal capacity of this firm. Unfortunately, we did not have any information on the allocation of transmission rights at the time of this study so this aspect of the market was not incorporated into our analysis.

We had access to very little information about the New York Power Pool market. Joskow and Frame (1997) note that the non-simultaneous import capability into the PJM pool is 3600 MW, and that this capability is reduced to 1700 MW when either the PJM Central Interface or the Eastern Interface is congested. What is needed is the transmission capability from New York into the Eastern region of PJM at times when the Eastern Interface is congested. Our information from Haglar-Bailly indicates that the capacity into New Jersey from New York is 400 MW. Joskow and Frame use 1700 MW, apparently assuming that all of the New York - PJM capacity is accessible to the Eastern region at times of congestion on the Eastern Interface. In any event, it is impossible to represent a transmission constraint in a meshed network as a single number, and we discuss below how the impact of additional transmission capacity can sometimes be approximated by shifting the level of demand. Our information on the generation capacities of the New York Power Pool (NYPP) is equally limited. We have assumed that there will be generation capacity available in eastern New York for export into New Jersey as long as there is enough transmission capacity to facilitate a trade. It is possible, however, that eastern New York may be as capacity constrained in generation as the Eastern region of PJM during periods of high demand. If that is the case than we have overstated the capability of fringe producers to compete in the PJM-East region during times of congestion on the Eastern Interface.

Table 1: Definitions of Regional Markets

Regional Market	States or Utilities Included	Year 2000 Peak (includes 10% reserve)	Base Case Transmission Capacity into New Jersey
New Jersey	ACE, DVP, JCP, PECO east, PSE&G, Dover, Easton, Vineland, IPPs	16,597 MW	NA
Western	PJM members in PJM Central and West, imports from ECAR, SERC, and western NYPP	33,220 MW	5300 MW
New York	Eastern NYPP members	NA	400 MW

2.2 Generation

Using data provided to us by Haglar-Bailly, we compiled stylized cost-curves of the various producers in the PJM pool. These curves consisted of step-functions where the "height" of each step was based upon the full-capacity average heat rate times the appropriate fuel price for that plant. The variable operating and maintenance costs for each plant were also included in this cost calculation. The "width" of each step was based upon the seasonally rated maximum capacity of each unit multiplied by that unit's forced outage rates. Unit capacities were not adjusted for planned maintenance since maintenance scheduling can be thought of as an implementation of a quantity strategy. Jointly owned units were divided amongst strategic firms according to their ownership shares. This was not necessary for plants jointly owned by various fringe firms since fringe capacity was aggregated into a PJM-West and PJM-East fringe cost curve. The cost curves for these various sets of firms are shown in figure 1. Only units that, according to the Haglar-Bailly data, are currently operating were included in this analysis.

The Cournot players were assumed to be the five investor-owned utilities that operate generation capacity in the PJM-East region. We treat Atlantic City Electric and Delmarva Power & Light as two separate Cournot firms. If these firms do indeed merge, this assumption would tend to understate the potential for market power. We assume that the IPP generation capacity in the PJM-East region will be operated by price-taking fringe firms. If this capacity is under some form of contract where the purchasing utility can be construed as "owning" the output from this capacity then this assumption will understate the potential for market power. IPPs provide a significant amount of generation capacity in New Jersey, over 2500 MW according to our data. Therefore the incentives of these producers may play a key role in the outlook for market power in that state. Four generation plants that, according to our data, are owned Dover, Easton, and Vineland were also assumed to be fringe production, as was the Conowingo Hydro facility.

2.3 Demand

The potential for market power in an electricity market can depend critically upon the level of demand in both the local market and in any markets from which imports may originate. We therefore performed our analysis on a series of demand levels ranging from current off-peak levels to the estimated peak in 2010. We calculate the Cournot equilibrium for demands starting at 7000 MW up to a level of 21000 MW at increments of 500 MW.

The demand levels for the western portion of the PJM-pool was represented as a multiple of the demand in PJM-East. The multiple was 1.999 for winter simulations and 1.758 for summer simulations. Therefore, if demand in the PJM-East region was 10,000 MW, it was assumed that demand in the PJM-West region would be 17,580. These multipliers come from load forecasts provided to us by Haglar-Bailly. They represent the average ratio of west-to-east demand for the months of January and September in the year 2000, respectively.

These demand quantities were used to "anchor" the demand curves used in our simulations. For the Cournot analysis we used a constant elasticity demand curve of the form $q = kp^{-\varepsilon}$ where ε is the elasticity of demand and *k* was adjusted such that the demand curve passed through the given demand level at a reference price. The reference price was $ 74.91/MWh. This is based upon the weighted average of the 1995 average revenue of the four investor owned utilities whose demand is located in PJM-East. This average was escalated at 2.5% to the year 2000 to produce 74.91.[11] Since this price figure includes fully bundled electric service, and we are trying to represent the revenues of generation companies, we need to separate off an estimate of the portion of these costs that are allocated to functions other than the production of energy. We used an estimate of $35/MWh out of this $74.91 that will be applied towards these transmission and distribution functions.

2.4 Other Factors

It is important to remember that this model, like any simulation of competition between firms, is a stylized representation of both the capabilities and behavior of the firms involved. There are many aspects of the PJM system that we are not incorporated into this analysis. The impact of many of these factors, however, can be roughly approximated by adjusting the levels of native demand. In this section, we summarize some of these factors and their likely impact on market power.

[11] These data are taken from the Energy Information Administrations *Electric Sales and Revenue, 1995* report, DOE/EIA-0540(95). The revenue figure for GPU-JC was consistent with exhibit MAG-SC-30.

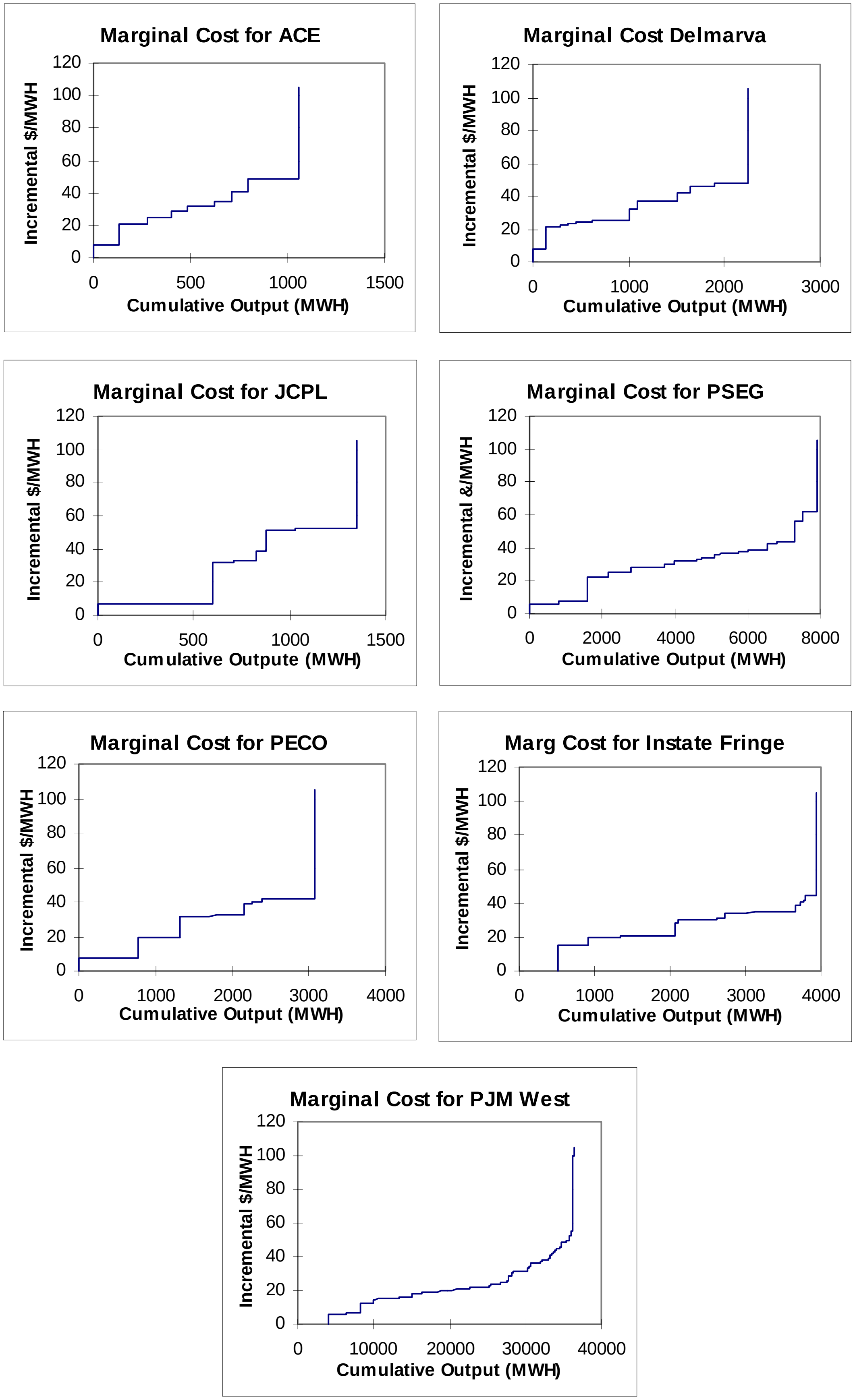

Figure 1: Marginal Costs of Firms

Reserve Margins

In this analysis we do not include any explicit adjustments for reserve margins or energy losses on transmission lines. Joskow and Frame report that a ballpark estimate of the reserve margins in the PJM pool is around 10%. The impact of the needs for reserves can be approximated by adjusting the demand upwards by the reserve percentage. This would apply to the demand curve's baseline or "anchor point" demand. Therefore, when interpreting the Cournot equilibrium results presented in the following sections, one would simply adjust this baseline demand. For instance, to approximate the impact of a 10% reserve margin on an hour when baseline demand is 10,000 MW, one would simply use the results when baseline demand, without reserve, is 11,000 MW.

Pump Storage and New Entry

The addition of inexpensive fringe capacity can be closely approximated by shifting the demand curve downward by an amount equivalent to the new capacity. Thus the "residual" demand seen by the Cournot firms has been reduced by the addition of fringe production. The same logic would apply towards the utilization of pump-storage capabilities *by fringe players*. The storage units would in effect add generation capacity to high demand hours, when prices are at their highest.

The impact of the addition of new storage or conventional generation capacity by Cournot players is more difficult to approximate. In the hands of a very dominant firm, the extra capacity may have little impact, since that firm would presumably be reducing the output from the units it already has. New capacity in the hands of a smaller Cournot player would probably decrease the extent of market power, although by less than if that capacity were owned by a fringe player.

Transmission Capacities and Losses

The effects of transmission losses and the capacities of the lines can sometimes also be approximated by shifts in demand when the outside markets are assumed to be competitive, as they are here. The same logic applies for an increase in the transmission capacity to markets *where there is abundant and inexpensive excess capacity*. However, it is important to remember that the expansion of transmission capacity into markets where there is little surplus generation capacity will have little impact on competition.

3.0 Cournot Algorithm

3.1 Fringe Firms

To analyze competition among the Cournot firms in this market, we first control for the effect of price-taking firms (small New Jersey producers, NYPP, and the PJM-West fringe) by subtracting the aggregate supply of these fringe firms from the market demand . From this, we obtain a residual demand curve that the Cournot firms in the market would face. To obtain the aggregate fringe supply at any given price, we add together the quantity that each of the price-taking firms would produce if it produced every unit of output for which its marginal cost was less than the price. We then subtract this quantity from the market demand quantity at that price to obtain the residual demand quantity at that price. The resulting residual demand function is more price elastic than the original market demand function. This is the demand over which the Cournot firms are assumed to compete.

$$D_r(P) = D(P) - S^f_{NJ}(P) - Min(S^f_{PJMW}(P), TR_{PJMW}) \qquad \textbf{(2)}$$

where *D(P)* is the market demand function, S^f_{NJ} and S^f_{PJMW} represent the fringe supply curves for the New Jersey and PJM-West regions, respectively, TR_{PJMW} represents the transmission constraint between PJM-West and PJM-East, and $D_r(P)$ is the residual demand curve faced by Cournot players in PJM-East. Fringe supply from NYPP into both PJM-East and PJM-West was treated as located within each of these regions.

3.2 Cournot Firms

Using the marginal cost functions of the Cournot competitors and a residual demand function, which is the market demand minus the fringe supply at every given price, we calculate the Cournot equilibrium iteratively. Using a grid-search method, we determine the profit-maximizing output for each Cournot supplier under the assumption that the production of the other Cournot suppliers is fixed. This is repeated for each Cournot firm: the first supplier sets output under the assumption that the other Cournot players will have no output, the second sets output assuming the first will maintain its output at the level that was calculated for it in the previous iteration, and so on. The process repeats, returning to each supplier with each resetting its output levels based upon the most recent output decisions of the others, until no supplier can profit from changing its output levels given the output of the other Cournot suppliers. Thus, at the Cournot equilibrium, each firm is producing its profit-maximizing quantity given the quantities that are being produced by all other Cournot participants in the market.

It is worth noting that although a constant elasticity demand curve with elasticity less than one would cause a monopolist to charge an infinite price, no one firm faces that demand curve. Each Cournot player faces a demand function that is the residual demand curve in equation (1) above minus the quantities being produced by all other Cournot players. Firm *i*, which is a Cournot player, faces demand

$$D_i(P) = D_r(P) - \sum_{k \neq i} D_k \qquad \textbf{(3)}$$

where *k* indexes firms that are Cournot players and $D_r(P)$ is the residual demand curve defined in (1). This demand will in general be much more elastic than *D(P)* at every price.[12]

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[12] Although a constant-elasticity demand function with elasticity less than one would yield an infinite price for a monopolist, equilibrium price will always be finite if there is positive output from a price taking fringe. To see that this is the case, note that with positive output from the price taking fringe, the residual demand faced by Cournot firms in a market will, at a sufficiently high price, always intersect the vertical axis.

3.4 Multiple Equilibria

One drawback of our treatment of the price-taking fringe is that the residual demand, being $D(P)$ minus the fringe supply, can have flat regions in it. This results from the fact that each plant is assumed to have a constant marginal cost up to capacity, causing the fringe supply curve to have flat regions. As a result, the demand curve faced by any one firm will also have flat regions and those flat regions will be associated with discontinuities in the marginal revenue curve that the firm faces. For a given firm, this can result in multiple local profit maxima. This in itself is not a problem since our grid-search method assures that the output derived is a firm's global profit maximum. However, this can also lead to multiple equilibria since small changes in the output of other firms can cause a given firm to make relatively large jumps in its own output.

Time limitations have prevented us from investigating whether multiple equilibria exist for many of the demand levels examined. The reader should keep in mind that the results reported here present one of potentially several equilibria. However, it is almost certain that the equilibrium with higher prices is the most profitable for each strategic firm. In a repeated market such as this one, it is reasonable to expect that firms would move towards the most profitable equilibrium point. Our past experience with other simulations lead us to believe that the equilibria reported here are the ones with the highest prices of any multiple equilibria that may exist.

4.0 Results

Figures 2 and 3 show the perfectly competitive and the Cournot equilibrium prices for the range of demands that we examined. All of our figures present the output as a function of the native load in PJM-East at the demand curves' anchor point of $74.91/MWh. The horizontal axes of these figures, therefore shows the demand level in this market when the price, *including* $35/MWh for transmission and distribution, is $74.91. The actual market demand resulting from these simulations will be different when the price is not equal to this anchor price. The equilibrium prices reported on the vertical axes of figures ?? and ?? report the *energy* price, after subtracting the transmission and distribution charges.

As noted above, we simulated demand elasticities of -.1, -.4, and -.9. The pattern is for Cournot prices to track competitive ones relatively closely for low and medium levels of demand, and then to greatly exceed competitive prices when demand is above some threshold level. One can see from these figures that the impact of market power at high demand levels is greatly reduced at higher elasticities. Furthermore, the threshold demand level at which the Cournot prices start to greatly exceed the competitive ones also increases at higher elasticities.

The output of each firm and the Cournot equilibrium price for each demand level are reported in the tables of Appendix 1. Our simulation allowed for a maximum price of $1000/Mwh. There are some demand levels where the Cournot price exceeds this level. The price is instead reported as > $1000. Also included in these tables is a calculation of the marginal cost of the system at the Cournot quantity, if the system were dispatched at least-cost. This is used to calculate a system-wide Lerner index, shown in figures 4 and 5.

It is interesting to note that higher elasticities tend to reduce the severity of market power in this market, but enlarge the scope of it. One can see from figures 4 and 5 that the Lerner index is much lower at high demand levels when elasticity is high. However, the Lerner index tends to be at .1 or higher for more demand levels when elasticity is higher.

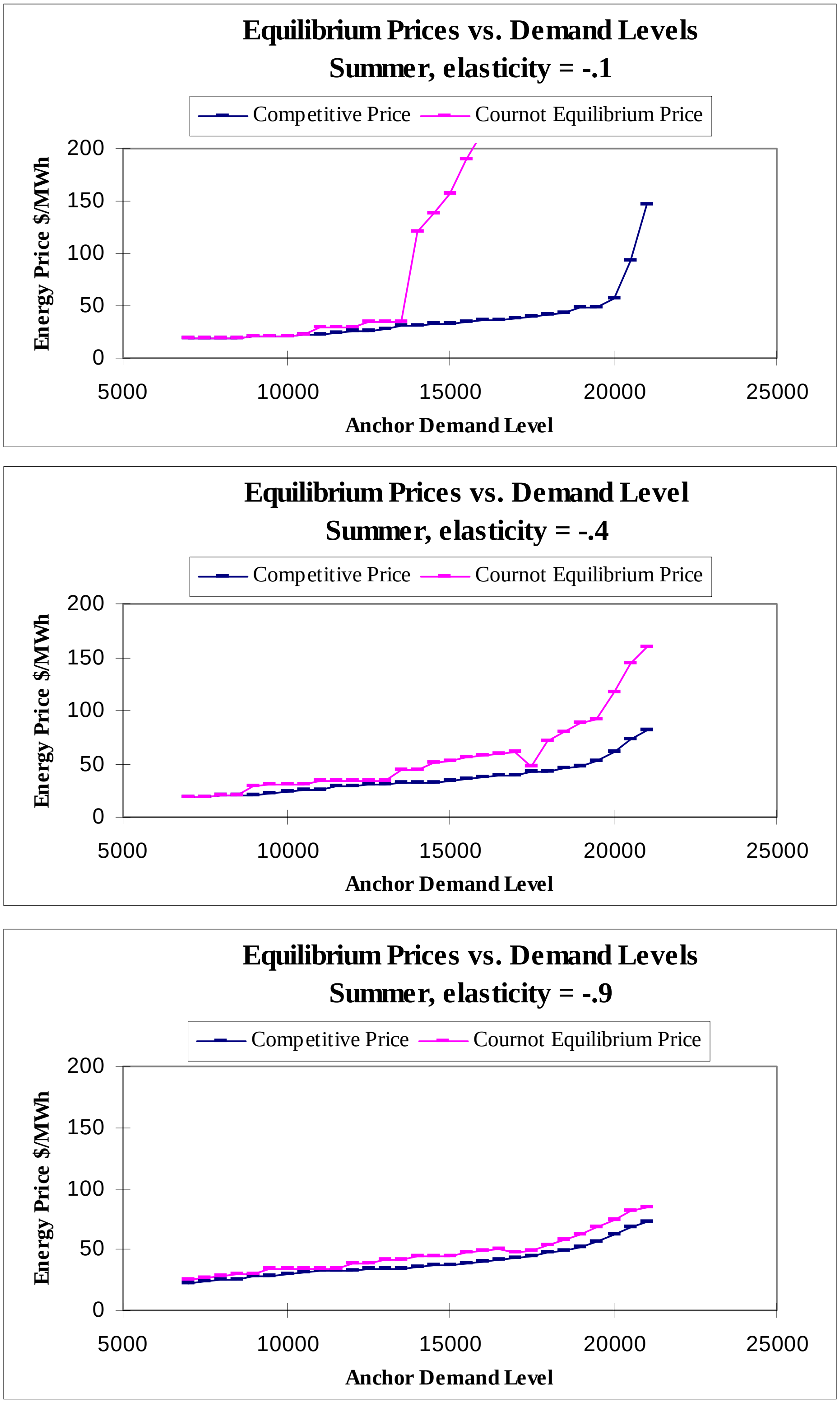
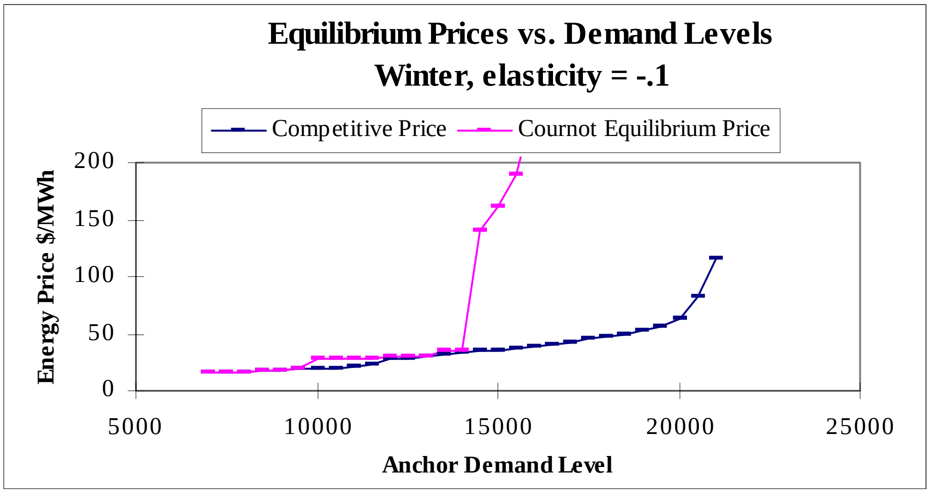
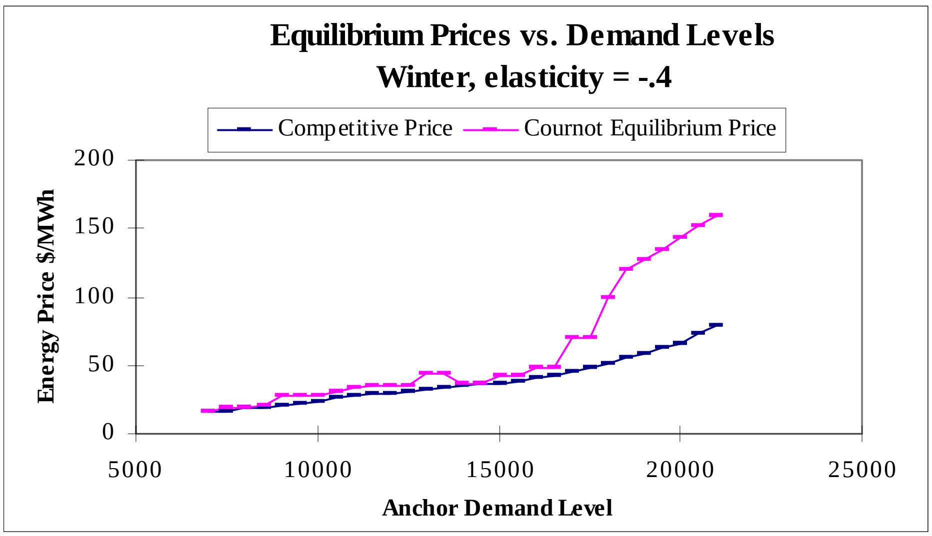


Figure 2: Equilibrium Prices for summer





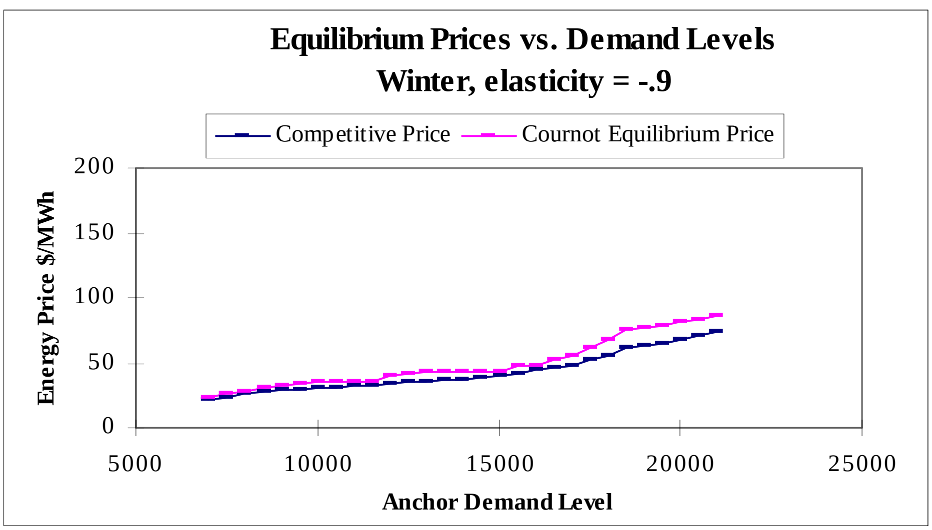


Figure 3: Equilibrium Prices for winter

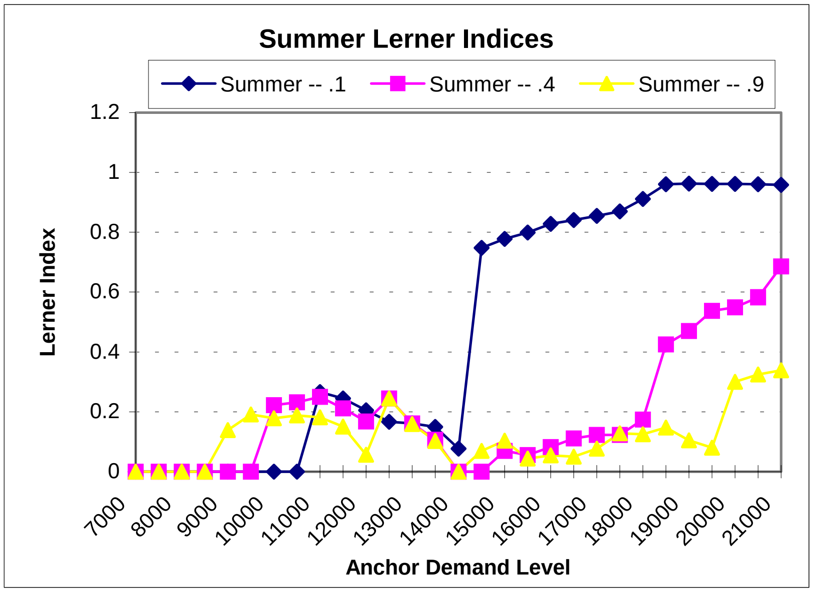


Figure 4: Lerner Indices for summer at Various Elasticities

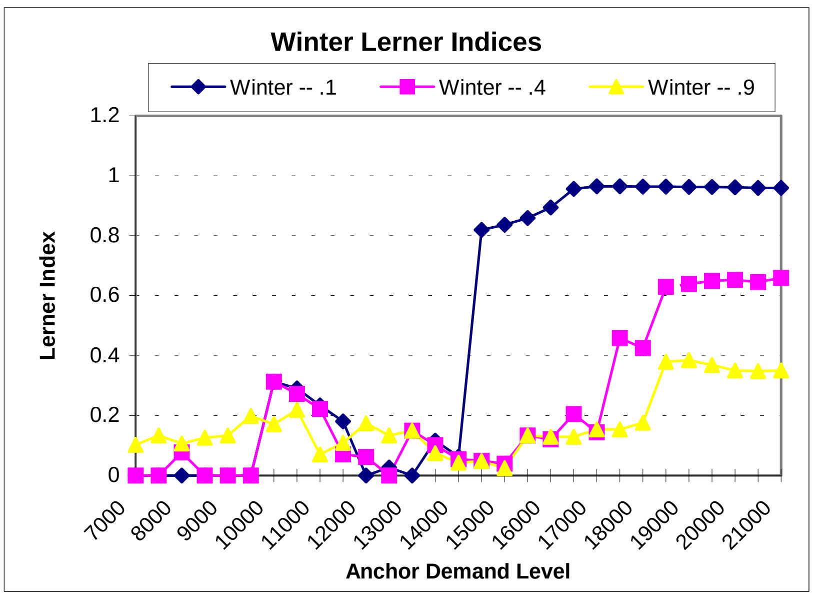


Figure 5: Lerner Indices for winter at Various Elasticities

Transmission Flows

At the lowest elasticity examined, -.1, the transmission path from PJM-West becomes congested at demands above 11,000 MW. The Cournot equilibrium prices begin to moderately exceed marginal costs, with a Lerner index between .2 and .3 (see ???). When demand rises above 14,500 MW, the Cournot equilibrium prices begin to exceed competitive ones by a factor of 4 or more. An examination of the output of PSE&G and the flows from PJM-West (Figure 6) shows that at the very high demand levels, the capacity in the western part of the pool is needed to serve western demand, and the amount available for export into the east declines steadily below 5300 MW.

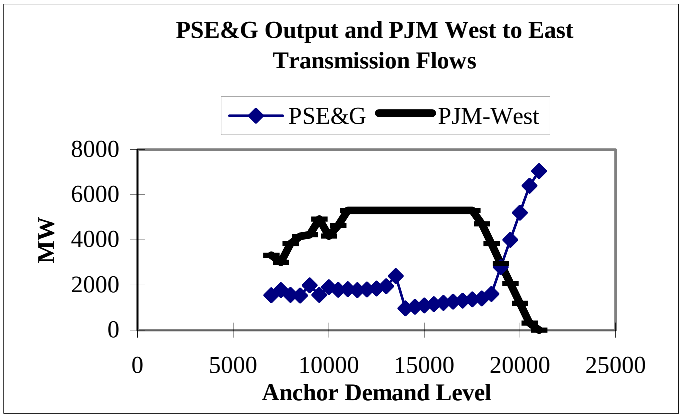


Figure 6: Outputs and Flows for summer, elasticity = -.1

It is informative to contrast this congestion pattern with the one that would arise if the market were perfectly competitive. Figure 7 shows that the flows from PJM-West reach the maximum of 5300 at only one demand level. One can see that one source of the increased congestion in the Cournot case is the reduced output of PSE&G relative to its perfectly competitive output.

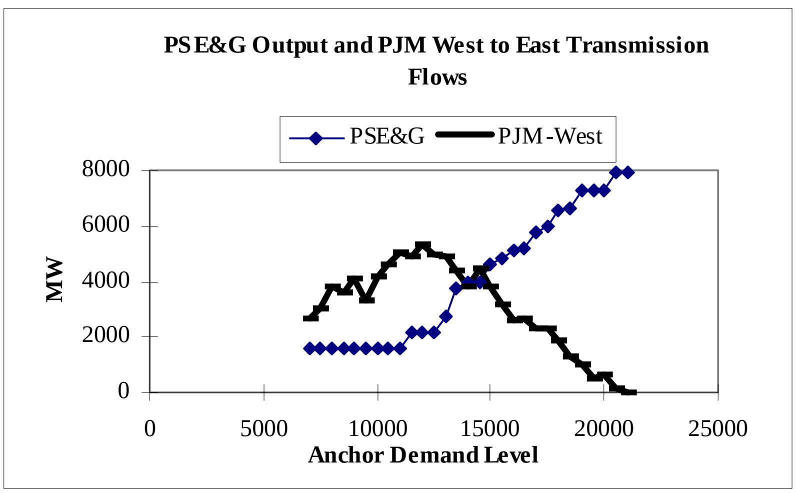


Figure 7: Outputs and Flows Under Perfect Competition in summer, elasticity = -.1

Figure 8 shows a forecast load-duration curve for the year 2000 for the combined loads of the 4 investor-owned utilities in PJM-East (excluding PECO). Demand, excluding reserve margins, exceeds 11,000 for roughly 2800 hours of the year and 14,500 for about 250 hours. The Cournot equilibrium therefore produces over 2500 more hours of congestion than the competitive equilibrium.

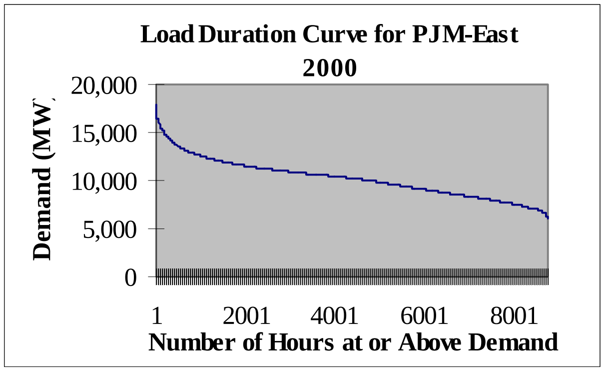


Figure 8: Load Duration Curve for PJM-East

Oyster Creek Retirement

We also examined the summer under the assumption that the Oyster Creek nuclear plant had been retired. This removes roughly 600 MW of capacity from one of the smaller Cournot players, JCPL. The impact is roughly comparable to removing that amount of capacity from the fringe: the demand levels at which both the modest and the extremely large price mark-ups begin are shifted down by about 500 MW (see Figure 9).[13]

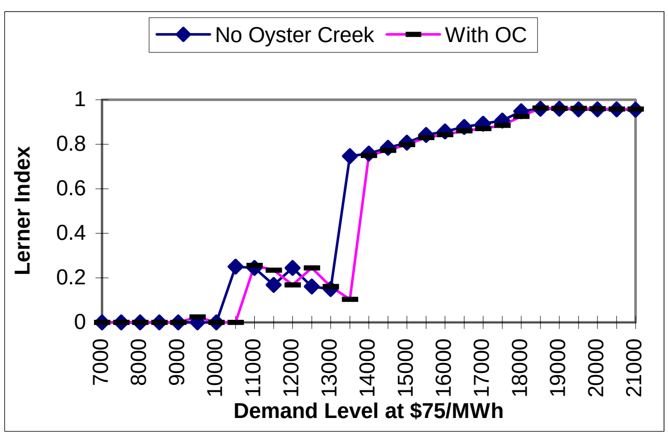


Figure 9: Lerner Index for Summer, elasticity = -.1

6.0 Summary

[13] Recall that we only simulated demand levels at increments of 500 MW.

We have presented the results of simulations of the New Jersey and PJM electricity m markets where some firms act strategically. These strategic firms were assumed to follow Cournot, (quantity) strategies. We have focused on the New Jersey, (PJM-East) market and have assumed that all generation outside of this region is dispatched competitively. We present Cournot equilibrium results for a wide range of demand levels, assuming that demand in PJM-West increases linearly with demand in the east.

We find that above certain threshold demand levels, there exist Cournot equilibria with prices substantially higher than perfectly competitive ones. At demands below these threshold levels, the Cournot equilibria produce relatively small mark-ups over competitive prices. These threshold demand levels, and the magnitude of the price mark-up strongly depend upon the elasticity of demand in this market. At higher elasticities, when demand is more responsive to prices, the threshold demand level increases and the mark-ups decline.

A significant factor in these results is the limited capacity on the transmission path from the western portion of the PJM pool. Above certain demand levels, there exist Cournot equilibria where that path is congested, and the price-mark ups increase rapidly. Our results indicate that transmission congestion is much more common when firms behave as Cournot players than when they behave competitively.

Because congestion of the west-east path is likely to occur frequently when firms act strategically, we have assumed that capacity located in the west, but owned by firms in New Jersey, would be dispatched competitively. However, we also find times in which the strategic reduction in the output of generation located in New Jersey affects prices throughout the PJM system. This happens when demand in both the west and east is very high, and the generation capacity in the east becomes constrained. In such circumstances, our assumption that western capacity would behave competitively is less appropriate. A more detailed analysis of the region, including the New York Power Pool and possibly other neighboring markets, would be needed to address many of these issues more accurately.

There are many factors that could not be considered in an analysis of this type. The impact of some of these factors, however, can be approximated by adjusting the level of demand in the market in question. For example, the impact of new generation or transmission capacity that increases the capabilities of fringe producers can be approximated by reducing the baseline demand. If there are relatively modest price mark-ups at demand levels below 14,000 MW in the absence of such factors, the entry of 1000 MW of new fringe production would imply that there would be only modest mark-ups for demands below 15,000 MW. The impact of capacity additions to Cournot firms, or transmission expansion to regions with constrained generation capacity, would have a more ambiguous impact.

These findings should not be seen as suggesting that deregulation and competitive restructuring are mistakes. Very few markets are completely devoid of market power. One must compare the prices consumers will face in a deregulated market with the outcome under the current regime or some other baseline. While the techniques we employ here could be used to address some of these questions, it would require a more detailed analysis of this market than we have thus far carried out.

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