Market Power in Electricity Markets:
Beyond Concentration Measures

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February 1999

Abstract

The wave of electricity market restructuring both within the United States and worldwide has brought the issue of horizontal market power to the forefront. Traditionally, estimation and prediction of market power has relied heavily on concentration measures. In this paper, we discuss the weaknesses of concentration measures as a viable measure of market power in the electricity industry, and we propose an alternative method based on market simulations and the use of plant level data. We discuss results from previous studies the authors have performed, and present new results that allow for the detection of threshold demand levels where market power is likely to be a problem. In addition, we analyze the impact of that recent divestitures in the California electricity market will have on estimated market power. We close with a discussion of the policy implications of the results.

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1. Introduction

Horizontal market power is one of the central issues surrounding electricity industry restructuring in the United States. There has been a great deal of discussion recently about how to best analyze the potential for market power in restructured electricity markets. Indeed, recent efforts by the Federal Energy Regulatory Commission (FERC) to streamline the process for merger analysis have focused primarily on this issue.[2] The FERC has proposed that market concentration measures be used as the foundation of a 'screening' process of proposed mergers.

However, traditional reliance on concentration measures is likely to be inadequate for the task. This is in part because concentration measures often depend upon historical data, such as energy sales and transmission congestion, which are of questionable value since the incentives of many firms will change significantly after restructuring. In part due to this weakness, the FERC has proposed substituting production-cost simulation results for historical data.[3] There is a fundamental flaw, however, in modeling approaches that simulate markets as if they were perfectly competitive, and then apply generic measures of the potential for exercise of market power, such as concentration indices. The flaw results from the fact a firm or set of firms, through the very act of exercising market power, will usually alter their production patterns in ways that violate the assumption of market-wide least-cost production.[4]

In place of concentration measures, researchers have begun to employ more sophisticated market analyses that attempt to capture the strategic aspects of competition in this industry.[5] These models are of course far from perfect. They do, however, offer several significant advantages over concentration analyses. One central insight from both theoretical and empirical models of restructured electricity markets is that a single market can at times exhibit very little market power and, at other times, suffer from the exercise of a great deal of market power.[6] The change between these states occurs when demand rises above levels for which several producers can contest to supply that load. This separation is more pronounced in the electricity industry because of the relatively limited production capacities of small producers, the widespread potential for transmission congestion, and the fact that electricity is expensive to store. As we discuss below, these factors combine to make the elasticity of demand for electricity a crucial factor in determining the potential impacts of market power. Concentration measures incorporate no information about the elasticity of demand.

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[2] See FERC, 1998a.

[3] This is the approach that has been proposed in FERC, 1998b.

[4] Each *firm* would want to produce whatever quantity it decides to sell in the most efficient way possible, but a firm exercising market power will restrict its output so that its marginal cost is below price (and equal to its marginal revenue), while other firms that are price-takers will produce units of output for which their marginal cost is virtually equal to price. Thus, there will be inefficient production on a market-wide basis: the same quantity could be produced more efficiently if the firm with market power produced slightly more and a price-taking firm produced slightly less.

[5] See Smeers (1997) for a discussion of the applicability of these models.

[6] von der Fehr and Harbord (1992) provide a theoretical discussion of how volatile demand can lead to very volatile prices since market power is more likely to appear at high-demand times. Wolak and Patrick (1996) provide empirical evidence of such a distinction in the United Kingdom.

In this paper, we discuss some of the strengths and weaknesses of the market power models that have been applied to the electricity industry. We illustrate some of the insights that can be gained from the use of game-theoretic models that can be used to simulate competition between a given set of competitors in a well-specified market environment. In doing so, we expand upon analyses we have performed on the California and New Jersey markets.[7]

2. Market Power Analysis

The fundamental measure of the exercise of market power is the price-cost margin,[8] which measures the degree to which prices exceed marginal costs. Prices above marginal cost lead to both inefficient allocations -- since consumption will be too low in response to prices that are too high -- and potentially to inequitable transfers from consumers to producers. In most industries, analysts are unable to measure price-cost margins, because costs are usually the private information of the producers. Often concentration measures, such as the Hirschmann-Herfindahl Index (HHI), are used instead as a first screen for the potential for market power.[9] Governmental agencies concerned with market power, such as the Department of Justice, have long relied on projected changes in concentration measures as a significant part of their analysis of the impact of structural changes in a market.

Although the guidelines that were developed by DOJ and largely adopted by FERC (see FERC, 1996) make clear that concentration measures should form only a component of a market power analysis, it is also common for both FERC and DOJ to use concentration measures as a screening tool. If a market concentration falls into a ‘safe’ level, often no further analysis is pursued. The market power analysis supporting the approval by FERC of market based rates for electrical energy in both California and the PJM pool, for example, was dominated by concentration measures (see WEPEX, 1996 and Joskow and Frame, 1997).[10] More recently, FERC approved the applications of certain firms to sell ancillary services in California based upon a market power analysis using concentration measures (see Henderson, 1998). Severe disruptions were experienced in the California market shortly thereafter.[11]

Although industry concentration and individual firm market share are often correlated with market power, this is not always the case. There are many factors beyond the number and size of firms in a market that impact the degree of competition within an industry. These factors include:

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[7] See Borenstein and Bushnell (1998), and Borenstein, Bushnell, and Knittel (1998).

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

[9] One justification for use of the HHI is that under certain conditions, most critically constant marginal costs and no capacity constraints, the HHI divided by the elasticity of demand is equal to the Cournot equilibrium Lerner index. See Tirole, 1998, page 221-223.

[10] See also FERC, 1996, which includes in the statement that “[b]y applying an analytic ‘screen’ early in the merger review process, the Commission will be able to identify proposed mergers that clearly will not harm competition.”

[11] Among other problems with the ancillary services markets, only a few firms were granted authority to earn market-based rates. See Wolak, Nordhaus, and Shapiro (1998).

- **The incentives of producers**: In the near term, it is likely that electricity markets will feature a diverse set of firms, including publicly owned utilities, unregulated generation companies, and traditional vertically integrated regulated utilities. Each type of firm is likely to respond differently to a given competitive environment.

- **The price-responsiveness (elasticity) of demand:** In markets where customers can easily choose not to consume a product, or to consume a substitute instead, producers cannot raise prices far above costs without significantly reducing sales. Conversely, a producer that knows that its product is absolutely needed can profitable raise prices to very high levels.

- **The potential for expansion of output by competitors and potential competitors:** Just as a producer with very price responsive customers cannot exercise much market power, neither can a producer faced with many price-responsive competitors. Transmission capacity into a region and available competitive generation capacity are the main factors in determining the potential for short-run competitive entry.

These factors are not captured by measures of the concentration of an industry. Concentration measures indicate the current distribution of sales or capacity, but cannot tell you what will happen 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 inelastic.[12] Because of these factors, concentration measures can often be an inappropriate 'screen.' Even though one firm may have a relatively small market share at a given demand level, it may be the case that if that firm reduced output, no other firm would be able to replace that supply because of cost, capacity or transmission constraints. The oligopoly equilibrium approach helps to analyze and detect such situations.

2.1 Simulating the Strategic Behavior of Firms

The approach to analyzing market power that we suggest here is to simulate the strategic behavior of firms in the market. These simulations are based on the cost and production characteristics of the actual set of generators that a firm owns, or the generators that it would own under a certain deregulation scenario. To fully specify the basis for such a simulation, we must describe the strategic variables that firms control and their assumptions about the behavior of other firms.

In most of the work that we have done in this area, we have implemented the oligopoly equilibrium approach by analyzing a variant of the Cournot-Nash concept of firm strategies and beliefs. The Cournot-Nash approach is to assume that strategic firms employ *quantity strategies:* each strategic firm chooses its quantity to produce taking as given the output being produced by all other strategic firms. We recognize, however, that not all firms are likely to behave strategically. Very small firms are more likely to simply take the market price as given and produce all output for which its incremental cost is less than the market price. Thus, we model

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[12] See Wolak and Patrick, 1997, for an analysis of the elasticity of demand of industrial consumers in the U.K. under real-time pricing.

only the larger firms as Cournot competitors. Very small firms are modeled as price-takers, both in their own behavior and in how they are viewed by strategic players in the market.[13]

In the context of an electricity market, the Cournot model seems an appropriate starting point, one that has been utilized in various forms to analyze electricity markets by Andersson and Bergman (1995), Oren (1997), and Hogan (1997). The other basic non-cooperative equilibrium concept, the Bertrand equilibrium, in which firms compete in prices, 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.

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 our work, because the capacity investments of the major players have already taken place.[14] 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.

Other oligopoly equilibrium concepts

To date, we have primarily utilized the Cournot-Nash concept in our studies of electricity markets, but there are other equilibrium concepts that should also be considered. It is difficult to point to a single economic equilibrium concept as the "best" approach for all markets. Each has strengths and weaknesses that make such a choice very much case specific. It is often the case that different models may produce different insights into potentially profitable strategic behavior. However, all of these insights can be of value to policy makers. As with any economic model, it is important to remember the implications of the model choice itself when interpreting its results.

One game-theoretic concept that has been prominently applied to electricity markets is the modeling of equilibria when bidders specify cost/quantity 'supply functions.'[15] One of the obvious attractions of a supply function equilibrium model is that it seems to correspond with the

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[13] One can model even the smallest firms as acting strategically, but it affects the outcomes of the simulations very little. While it is true that even a very small firm might be able to profit by restricting output if demand is very inelastic and the supply of other firms is at their capacity, larger firms will have a stronger incentive to restrict output in almost all circumstances. When the larger firms restrict their output, the incentives for smaller firms to do so are diminished. Thus, in equilibrium the largest firms in the market (who still might have a small market share) are the most likely to act strategically.

[14] 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 in 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 actually provide output in a given hour. We discuss the qualitative implications of these constraints on our market power model later in this paper.

[15] See Green and Newbery (1992), Green (1996), and Rudkevich, et al. (1998), for examples of this approach.

actual institutions in many electricity markets. The strategies of firms are actual price-quantity bid functions, rather than the inflexible quantity bid given by the Cournot model. It is also important to note that supply-function competition can produce results that are closer to the competitive outcome than those produced by the Cournot model.[16]

However, the supply-function model also has some weaknesses that may limit its usefulness when applied to certain electricity markets. In some markets, trades do not occur exclusively, or even primarily, through a supply-function bid process. Bilateral trading of specified quantities is common in many restructured markets around the world, as are futures markets and different forms of spots markets. In many of these markets, firms bid not only energy prices, but also startup costs, ramping rates, and other supply characteristics. The supply function approach also 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.[17] Overall, the supply function approach approximates one important aspect of many restructured electricity markets more accurately than the Cournot approach, but it is not as flexible as the Cournot approach in incorporating other institutional aspects of these markets. Furthermore, the supply function approach produces multiple equilibria, and the diversity of these equilibria grows as the uncertainty of demand is reduced.[18] The Cournot equilibrium represents an upper bound on supply function equilibria and is generally easier to calculate, thus it may be a more appropriate screening measure of the potential for market power.

Finally, neither the Cournot model nor the supply-function approach addresses issues of collusion. In both of these models, it is assumed that any exercise of market power would be unilateral by each firm. The ability of a group of firms to collude will depend on many factors, including the level of concentration, the ease of new entry or output expansion by fringe firms, the frequency with which prices are set, the repeated nature of firm interactions, the ability of firms to monitor the behavior of rivals or potential collusive partners, and the homogeneity of cost attributes across firms. Unfortunately, economic models of collusion generally offer little practical guidance about diagnosing collusive exercise of market power. Thus, our analysis does not directly capture the potential for collusive outcomes.

2.2 Entry, Exit, and Long Run Considerations

Both the concentration measures and the oligopoly models we have discussed focus on the short run in that they do not take into account the possible entry of new firms or generating plants, or the possible exit of existing firms or plants. Large profits among existing generators could lead to entry of new firms and plants that would drive down prices and dissipate any extranormal profits. The speed with which that would occur is, of course, an empirical question, and the decision of

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[16] See Klemperer and Meyer (1989) and Green and Newbery (1992).

[17] This is due in part to the fact that, to date, supply function models have relied upon the assumption that the slope of the demand function does not vary across time periods (or demand levels). The introduction of a significant price-taking fringe and of transmission constraints results in demand curves that are 'kinked' at the points at which these constraints become binding. The slope of demand is therefore not only changing as demand increases, but this change is endogenous to the output decisions of the strategic firms.

[18] In fact, the price in these equilibria can range from marginal cost to the Cournot equilibrium price. See Bolle (1992).

how quickly entry must respond to high prices in order to eliminate the need for government intervention is a policy question. We do not attempt to address either of these questions here. Rather, we point out that any tool used for analyzing short-run exercise of market power will be subject to this same critique. Evaluation of short-run market power – whether based on concentration measures, oligopoly equilibrium simulations, or some other approach – is only a part of the analysis one must do before determining the need for government oversight of competition in the industry.[19] It is clear that some such evaluation of short-run market power is, and will remain, part of the market power policy analysis, so the most effective tool for doing this evaluation should be used. Furthermore, if the hypothesis that entry will dissipate market power is to be tested, one needs an effective approach to carrying out such a test, as well as a benchmark to which the results can be compared.

Some analysts of the electricity industry have raised the concern that price-taking behavior on the part of every firm is simply too strict of a standard to be used as a benchmark. They argue that it is unrealistic to think that no market power will exist, since there is market power present in most markets. We recognize that market power exists in many markets, and that even with some market power present in the electricity industry, the result is still likely to be an improvement over traditional regulation. Nonetheless, we must also point out that there are many markets in which virtually no market power exists: most agricultural and natural resource markets, for instance. These industries are notable for producing virtually homogenous products and selling them over a large geographical area, characteristics that bear an important similarity to the electricity industry. Thus, while the presence of some market power should not be grounds for declaring deregulation of electricity generation a failure, neither should it be accepted as inevitable based on observation of other industries.

A more extreme view than the inevitability of market power is the view that market power is *necessary* to allow firms to cover their total costs of operation. In the absence of market power, the argument goes, marginal cost pricing will leave nothing to cover fixed costs and firms will not be profitable enough to survive. This view represents an unfortunate confusion about the economics of competitive markets. Price-taking behavior, the manifestation of competitive markets, means simply that every unit of output that can be produced at a marginal cost below the market price is being produced and every unit of output that can be produced at a marginal cost above the market price is not being produced. Thus, most, and in some cases all, output produced is produced at a marginal cost below the market price, and the difference between price and the marginal cost of each unit of output makes a contribution towards fixed costs. During very high demand times, for instance, price spikes will occur even in competitive markets as price rises to ration demand to the available supply. In a competitive market, however, all output that can be produced at a marginal cost less than the market price will be produced, and no generator will inflate its offer bid in an attempt to raise the market price.

If the total contribution generates more revenue than is necessary to cover the fixed costs of some type of generation, then in a competitive market with no barriers to entry, new generation of that type will enter the market. Conversely, if the total contribution generates less revenue than is

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[19] This is made clear in the DOJ/FTC merger guidelines, which form the basis for FERC's proposed approach to market power analysis.

necessary to cover the fixed costs of some type of generation, then some generators of that type are likely to exit. When exit occurs, the supply curve in the industry shifts in and the equilibrium market prices rise, so that all remaining firms earn higher prices and great contributions to fixed costs. In a competitive market, this process of entry and exit occurs until, in long-run equilibrium, all generators in the market are able to cover their fixed costs and no other generator could enter and cover its fixed costs at the current market prices. There is no economic argument for the necessity of market power to ensure the viability of the industry.[20]

Note that this does not mean that all current capacity in an industry will be able to cover its sunk investment costs or even its fixed going-forward costs in a deregulated market. Some firms or generating units may have to exit the market because they cannot cover their total going-forward costs of operation.[21] This can occur because such generators are just not sufficiently efficient to be viable in a competitive market, or because there is simply too much capacity in the market and some of it must exit in order for market prices to rise to a level that allow the remaining firms to break even as an outcome of the competitive supply/demand process.[22]

3. Oligopoly Simulation Methodology

In this section we describe the modeling approach used for calculating the results presented in section 4. We first describe how demand was modeled and then discuss the more difficult supply modeling issues.

3.1 Market Demand

In almost every electricity market that we, or others, have examined there is little potential for market power in off-peak, low demand hours. In many markets, however, there may be significant potential for market power during peak hours. This is due, in part, to the fact that when demand rises beyond a given level, both the transmission and generation capacity of potential competitors becomes exhausted, leaving the residual market to just a few dominant firms on the margin.

Because of this pervasive characteristic of competition in electricity markets, we examined a broad range of demand levels in the markets that we have studied. By a range of demand levels,

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[20] There is a related argument about whether the competitive market then results in the socially efficient level of capacity in the market. It in straightforward to show that if there are not significant economies of scale in production of capacity or energy (significant enough to make the industry a natural monopoly or oligopoly), then the result of competitive pricing will be the efficient level of capacity investment.

[21] As is well-understood by most observers now, there is no reason to consider sunk costs of the firm in this discussion, since the firm’s operating decisions should not be affected by its sunk costs.

[22] The DRAM memory market is an excellent example of the latter case. Very large investments in DRAM fabrication plants during the mid-1990s led to excess capacity that depressed prices and did not allow some firms to cover their fixed costs of operation. In this competitive industry, the result was that some firms exited and almost no firms were able to cover their sunk investment of building the plants. As some firms exited and demand grew, the remaining plants, however, were able to cover their fixed going-forward costs.

we, in effect, mean a range of demand *curves*, since we assume that demand is at least somewhat price-responsive. Since most electricity customers today face a constant marginal price for electricity, we fix our demand curves to reference points that relate to currently observed or forecast price-quantity pairs. In other words, our demand curves are set so that the market demand, at current prices, would equal the current demand levels. Figure 1 illustrates the construction of the demand curves used in the simulations. The demand function D_1 is chosen such that at current prices, market demand would be 10,000 MW, while D_2 is defined such that market demand would be 25,000 MW at current prices. In the results presented below demand functions are identified by their "anchor" demand quantity (e.g. the anchor quantity of D_1 is 10,000). To account for the fluctuations between peak and off-peak demand, we vary this "anchor quantity," while keeping the reference price the same. For our simulations, we utilized constant elasticity demand curves of the form $D(p) = KP^{-\varepsilon}$ where ε is the elasticity of demand and K is a constant set according to the anchor demand level.

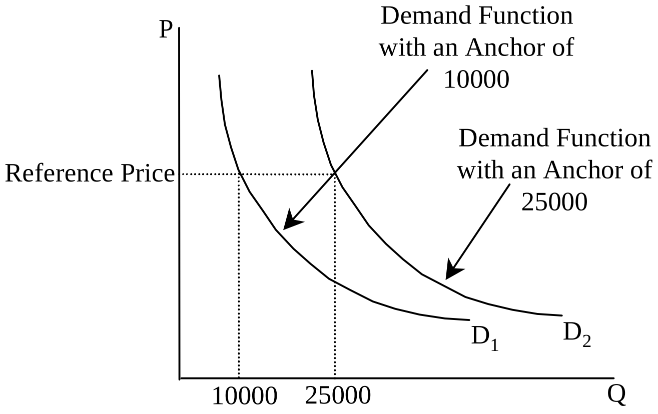

Figure 1 — Simulation Demand Functions

3.2 Market Supply

The cost curves of the firms were constructed using plant level data on the capacities, heat rates, fuel and maintenance costs of each generation unit.[23] The capacity of each generation unit was 'derated' according to the forced outage rate of that unit, yielding an expected capacity. The cost-capacity pairs of each unit were then combined to produce, for each firm, a step-function of cost of total output.[24]

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[23] For the California market, the results presented here assume that the hydro resources of each California firm are operating at its minimum flow level. This is approximately the condition that obtains in the late fall and early winter, when market power is most likely to be of concern. Hydro production is considered to be costless, and is represented as a zero-cost step in the cost function. Bushnell (1998) examines the potential market impacts of the strategic manipulation of hydro-electric resources.

[24] This process is described in more detail in Borenstein and Bushnell (1998).

3.3 Cournot Simulation Algorithm

In general firms were divided into two categories. Very small firms that it appeared could not credibly attempt to affect the market price under any normal demand conditions were treated as price-takers. Some large firms, either because they were publicly owned, or were themselves large consumers of electricity, were also included in the price-taking group of firms. These firms were modeled as simply producing every unit of output they could for which their marginal cost was less than the market price. Generation that will continue to operate under inflexible, non-market based agreements, such as some nuclear and independent power facilities, was also treated as price-taking and added to the fringe. Larger deregulated generators that it appeared could affect the market price under some conditions were assumed to follow Cournot strategies.

Treatment of Fringe Firms

To analyze competition among the Cournot firms in this market, we first control for the effect of the fringe by subtracting the aggregate supply of these 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. Fringe generation units operating outside of the analyzed market face the additional constraint that their exports into the market cannot exceed the respective transmission limits. We then subtract the quantity that would be supplied by the fringe firms at every price from the market demand quantity at that price yielding a residual demand quantity at that price. The Cournot firms compete over this resulting residual demand function which is more price elastic than the original market demand function. Formally, the demand function faced by the Cournot firms is represented as:

$$D_r(P) = D(P) - \sum Min(S_i^f(P), TR_i) \qquad \textbf{(1)}$$

where $D(P)$ is the market demand function, S_i^f represents the fringe supply curves for fringe firm i and TR_i represents the transmission constraint faced by the ith fringe firm. Thus the supply capability of the fringe can be constrained by transmission limits. The function, $D_r(P)$ is the resulting residual demand curve faced by Cournot players in their respective markets.

Cournot Firms

Using the above definition, we construct the residual demand curve faced by the Cournot players for a wide range of market demand levels. The use of these demand ranges allows us to accurately pinpoint demand levels where market power problems are likely to exist. For each demand level, 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.

At each iteration, every Cournot player faces a demand function that is the residual demand curve in equation (1) above minus the production quantities of all other Cournot players. Therefore, although the market demand curve is a constant elasticity demand curve with elasticity less than one (which would cause a monopolist to charge an infinite price) no one firm faces that demand curve, insuring a finite price. More formally, every Cournot player *i*, faces demand

$$D_i(P) = D_r(P) - \sum_{k \neq i} D_k \qquad \textbf{(2)}$$

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.[25]

Multiple Equilibria

One drawback of our treatment of the price-taking fringe is that the residual demand, defined as $D(P)$ minus the fringe supply, can contain flat regions. 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.[26]

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

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[25] 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.

[26] The multiple equilibria problem in the Cournot analysis is quite different from the one that occurs with a supply function analysis. It appears here because we attempt to model explicitly the discontinuities in fringe firm cost functions, a problem that is ignored in most of the supply curve analysis because there is not tractable way to deal with it in that setting. (Rudkevich, *et al*. (1998), attempt this, but must restrict their model to symmetric strategic players only in order to get solutions.) Note that in cases where market power is most acute, which are usually cases in which the competitive fringe has little effect on price at the margin, the multiple equilibria problem is not present in the Cournot analysis.

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.

3.4 Sensitivity Analysis

It is important to remember that this model, like any quantitative simulation of competition between firms, is a stylized representation of both the capabilities and behavior of the firms involved. By evaluating the potential for market power over a broad range of potential demand levels, we can estimate the sensitivity of these results to factors not directly represented in the model and to changes in some of the model parameters. The impact of many of these factors 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.

Reserve Margins

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. 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. This will accurately reflect new fringe capacity so long as it is inexpensive enough to be "inframarginal" so that it would certainly be operating at the demand level being analyzed. This is a safe assumption for the periods when market power is most acute. 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. More to the point, if the Cournot players were to acquire new capacity, the analysis would have to be rerun to incorporate all of the strategic effects of such a change.

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 we have assumed. 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.

4. Results of Analysis of US Markets

In this section we provide examples of how an equilibrium analysis can yield insights into the competitive nature of markets beyond those provided by concentration indices. These examples build upon studies we have performed on electricity markets in the U.S.[27] They make clear that the potential for market power depends heavily on the amount of demand in a given market. Fringe production capacity, demand elasticity, and transmission capacity also play key roles in the competitiveness of our simulated markets.

Production Capacity of Non-Strategic Producers

A brief examination of the California electricity market reveals a market with a diverse set of producers. California is home to a large amount of non-utility generation, using both fossil-based and renewable fuel technologies. Furthermore, there are several municipal utilities of various sizes, including the Los Angeles Department of Water and Power (LADWP), the third largest producer in the state. When one also considers imports into the state from other regional markets, such as the Pacific Northwest and the desert southwest, this market indeed appears quite *unconcentrated* by traditional standards.

We found, however, that under the generation ownership that existed in 1997 there would be a significant potential for market power in hours with high demands. For reference, note that the load levels in the California ISO have ranged from roughly 15,000 MW up to roughly 45,000 MW during 1998. These ISO loads do not include the demand of some municipal utilities in California, including LADWP, which amount to roughly 10-15% of the ISO total. At the higher demand levels, many producers reach their full output capacities. The disciplining effect of those producers on strategic behavior by the remaining firms therefore is severely reduced. These remaining producers can profitably reduce their output, knowing that most of their capacity-constrained competitors will be unable to respond with increased production. Ironically, when such behavior occurs, the concentration of the market appears to be reduced, since the strategic firms – the largest producers – are in fact withholding production, and therefore reducing their market share. We found many cases in which the price-cost margin increased as concentration declined.

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[27] For a complete description of the data and methodology used see Borenstein and Bushnell (1998) and Borenstein, Bushnell, and Knittel (1998).

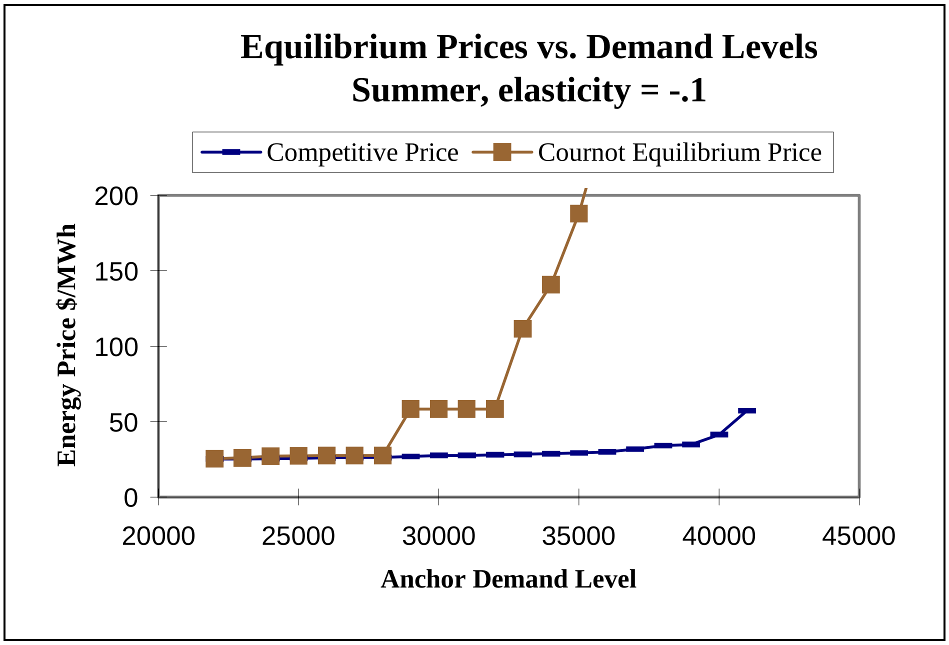

Figure 2— California Cournot Prices Relative to Perfect Competition

Figure 3 illustrates this point. On the horizontal axis we plot the "anchor quantity" of our demand curves. In other words, the demand in the market if prices were equal to those today.[28] The final market quantity from our simulations varied from these levels as the Cournot equilibrium prices were sometimes far higher than current prices. In Figure we plot the perfectly competitive price – the result if all firms behaved as price takers – along with the Cournot equilibrium price for "anchor demands" ranging from 21,000 MW to 42,000 MW. The Cournot price closely tracks the perfectly competitive price at low demand levels and then rises sharply beyond a certain threshold level, around 27,000 MW. Prices at this point begin to rise because an increasing number of competitive firms reach their maximum capacity. The two largest firms, Pacific Gas & Electric (PG&E) and Southern California Edison (SCE), then find it profitable to reduce their output and drive up prices. The resulting effect on concentration is that the market appears most concentrated at demand levels where these two firms are not trying to reduce output and, thus, markups are low. This is demonstrated in Figure 2, where the HHI and the Lerner index of markups are both plotted over different anchor demand levels. The Lerner index, defined as (P-MC)/P, ranges from zero when price is equal to marginal cost to near one when marginal cost is a vanishing proportion of the price charged to consumers.

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[28] For our study of California, our reference price was based upon a forecast by the California Energy Commission of the statewide average price in the year 2000. This price was 9.3 cents/kWh.

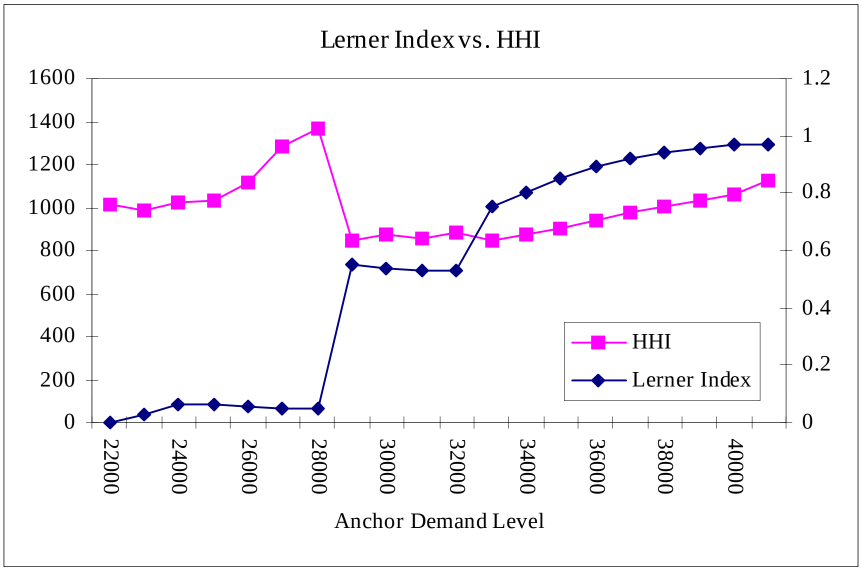

Figure 2 –- Lerner Index versus HHI Index

California divestitures of generation plants

Originally, the two largest investor owned utilities in California, Pacific Gas and Electric (PG&E) and Southern California Edison (SCE), were pressed to divest one-half of their gas-fired generation capacity. Although this original divestiture[29] did have a significant impact on the equilibrium prices in our model, the potential for substantial market power still remain. Eventually, both PG&E and SCE announced plans to sell off *all* of their gas-fired generation. Most of these transactions have been negotiated, and the transfer of ownership of most of these plants has been finalized during 1998. As Table 1 indicates, the generation capacity of these two formerly dominant firms have now been divided into 8 highly decentralized generation portfolios. The impact of these additional divestitures on equilibrium prices is significant. Figure 3 presents the equilibrium prices under the originally proposed divestiture as well as the actual divestiture. The results illustrate that the current divestiture proposal is likely to have a far greater impact on equilibrium prices in the California market than the original proposal. Although, there still remain demand levels where market power can be a problem, the threshold value where this is likely to occur is far greater under the current divestiture plan, relative to the original proposal.

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[29] In this case, each set of units was divided into roughly equal lots. This created one additional northern Californian firm out of half of PG&E's gas generation and two additional southern Californian firms, each controlling roughly half of SCE's current gas generation capacity. These new firms were assumed to be Cournot players.

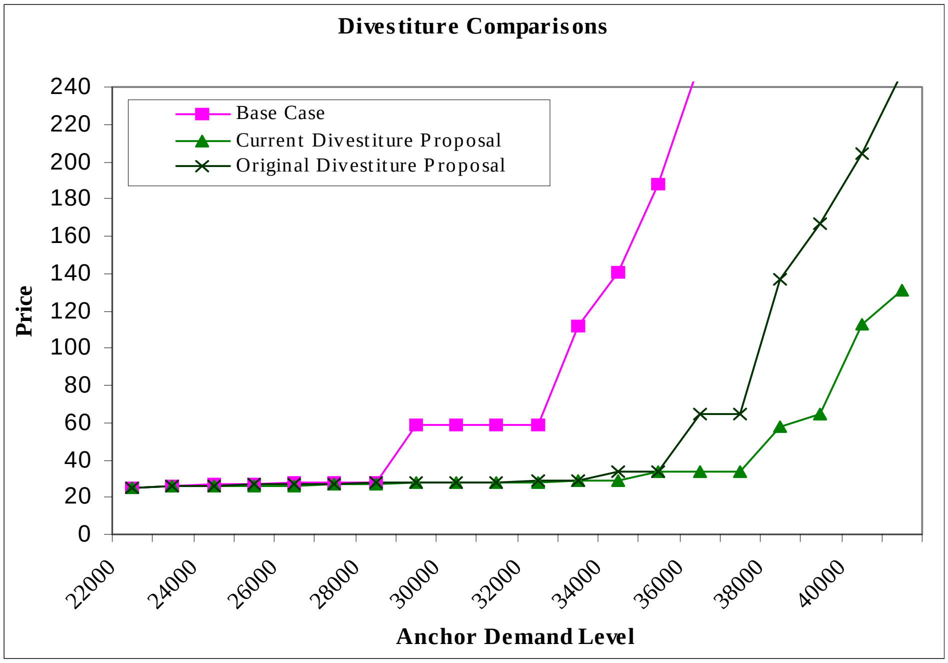

Figure 3 — The Impact of Asset Divestitures

Table 1 — Pre and Post Divestiture California Thermal Capacity

	Pre Divestiture (MW)	**Post Divestiture (MW)**
PGE	8083	782
SCE	12314	1378
New Firms		
Duke		2306
AES		3705
Houston		3554
NRG		1445
TCK		249
unknown		3093

The Impact of Demand Elasticity

One of the reasons that extreme price mark-ups can be sustained at demand levels where fringe capacity is constrained is that demand for electricity currently is not very price responsive. When this is the case, a larger firm may be able to increase profit by unilaterally decreasing its output since output reductions have a substantial impact on price. Such reductions lead to higher retail rates and consumer losses. In contrast, if the amount of electricity demanded is responsive to changes in price, then reductions in output by a single firm lead to small price increases and therefore a loss of profit. Only if firms are able effectively to collude in joint output reductions is price likely to be substantially above cost when demand is highly elastic.

Indeed, our analyses of the California and New Jersey markets confirm the importance of the elasticity when exploring the likelihood of market power in a restructured electricity industry. The policy implications from these results are clear. Policies that make consumers more responsive to real time prices can have dramatic effects on equilibrium prices and may be more effective than more traditional policies designed to combat market power, such as increases in transmission limits and generation capacity. This point is highlighted in Figure 4, which illustrates the equilibrium prices found in a restructured California market under three alternative scenarios; a demand elasticity of 0.1 with the current ownership of assets, a demand elasticity of 0.1 under the forthcoming divestiture of PG&E and Southern California Edison gas units, treating the newly created firms as Cournot players, and a demand elasticity of 0.4 with the current ownership of assets. The results illustrate that increasing the elasticity of demand from 0.1 to a still relatively inelastic level of 0.4 produces substantial decreases in prices. At high demand levels, the price reductions are greater even than those under divestiture.

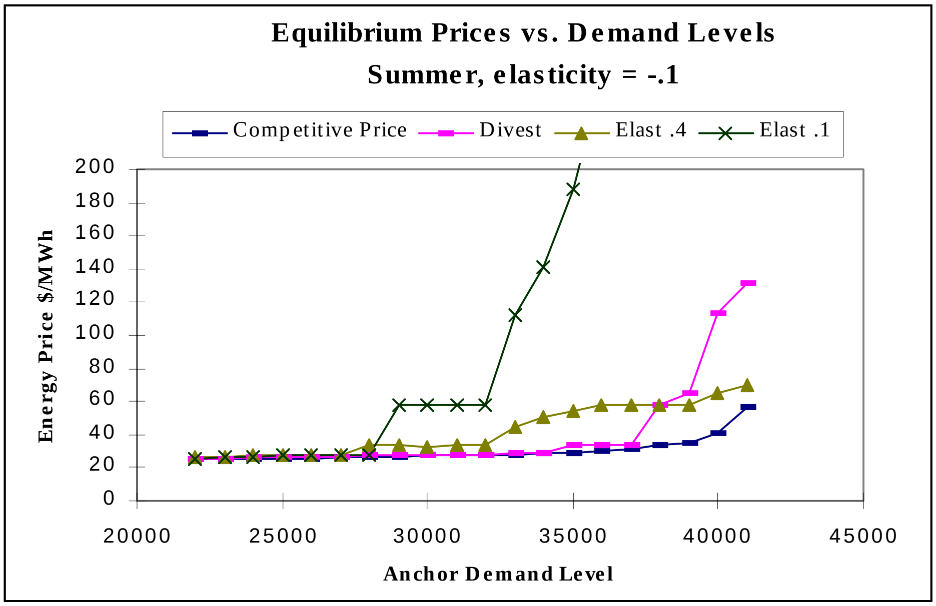

Figure 4 — The Impact of an Increase in the Responsiveness of Demand

The Potential for Strategic Use of Transmission Constraints

We have demonstrated in our work that limits in transmission capacity can have important impacts on the level of competition in certain markets by restricting the potential short-term entry into a given market. It is important to note that this effect is likely to occur much more frequently in deregulated markets than would be apparent from simply analyzing historical congestion under regulation. Some strategic firms, knowing that the scope of imports is limited by transmission constraints can profitably restrict output, thereby increasing imports and congestion on transmission paths into the strategic firm's region. Conversely, increasing transmission capacity into a region can have strikingly large impacts on the competitive health of that region.[30]

Some examples from a preliminary study that we have made of the electricity market in New Jersey help illustrate this point. The eastern portion of the PJM (Pennsylvania, New Jersey, and Maryland) pool at times constitutes a load pocket. An examination of historical congestion patterns[31] reveals that the transmission flows between the western and eastern portions of the pool have seldom reached the limits of that path. Flows along this path, however, have been within 500 MW of these limits far more often. This indicates that firms that own generation within the eastern portion of the pool might be able to profit from reducing output slightly and inducing congestion along this path.

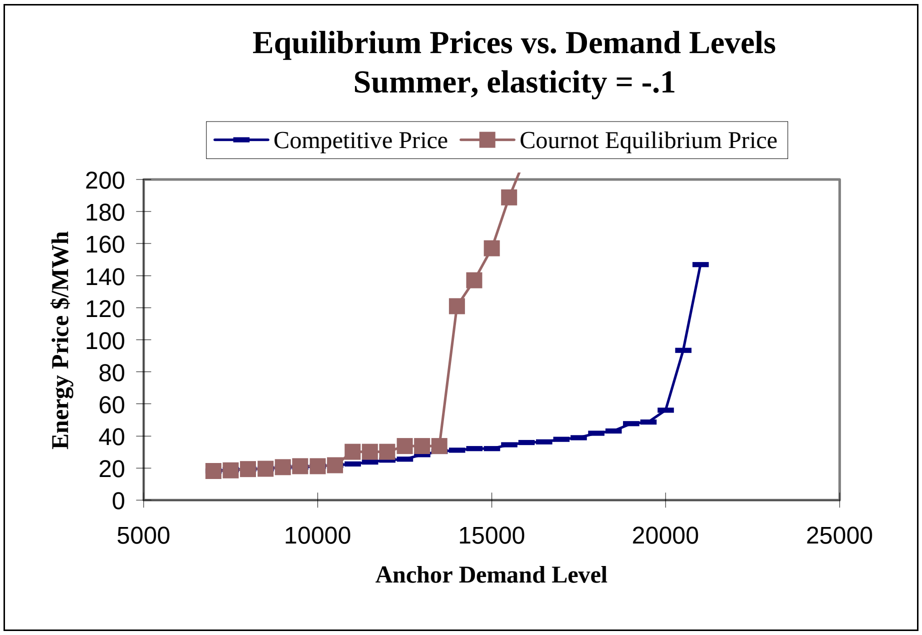

Figure 5 — PJM-East Cournot and Competitive Prices, Summer Costs and Capacities

Our Cournot equilibrium analysis indicates that, at high demand levels, this is the case. We again examined a broad range of demand levels by varying the “anchor quantities” of the demand curves used in our equilibrium calculations. As with the California market, we find that there is almost no market power at low demand levels, and that Cournot equilibrium prices rise steeply with demand above a certain threshold level. Figure 5 illustrates our results for a demand elasticity of 0.1.[32] The divergence of competitive and Cournot equilibrium prices are closely related to the level of congestion along the PJM west-to-east interface. Indeed, a comparison of the west-to-east flows under the assumption of perfect competition with those that arise when firms in the east act as Cournot competitors (Figure 6) reveals that the occurrence of congestion greatly increases when firms in the east act strategically.

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[30] See Borenstein, Bushnell, and Stoft (1998).

[31] See Joskow and Frame (1997).

[32] In calculating these equilibria, we assumed that generation units located in the western portion of the PJM pool, including those owned by firms located primarily in the east, would be dispatched non-strategically. The study is described in detail in Borenstein, Bushnell, and Knittel (1998).

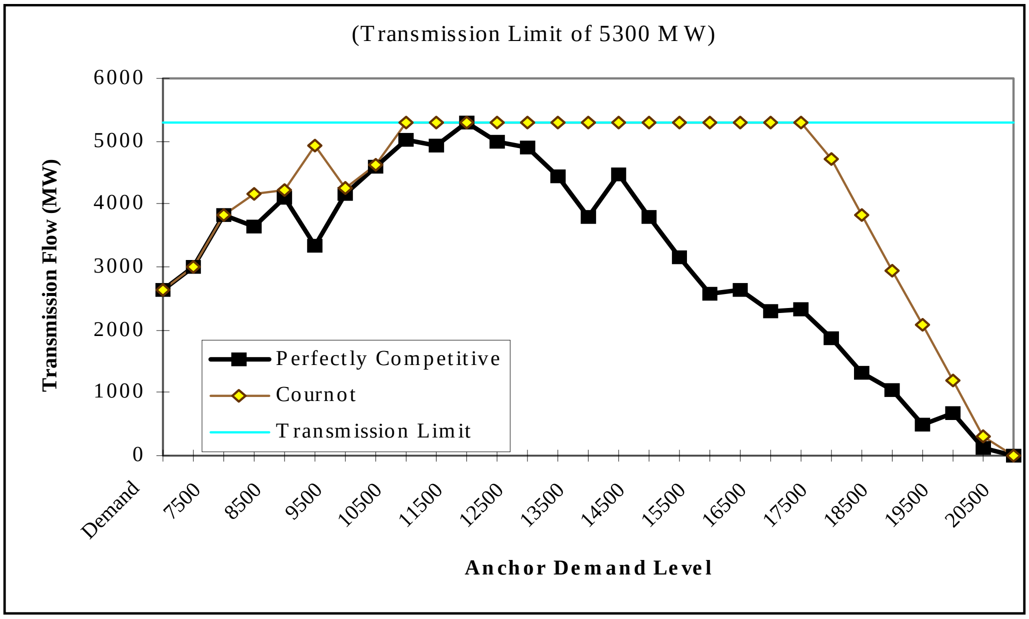

Figure 6— PJM West to East Transmission Flows

5. Conclusions

The current move by governments to restructure electricity markets – allowing the competitive interactions among many buyers and sellers to set price – has spurred research into the likelihood of market power in electricity markets. Policy makers need to estimate the ability of firms to sustain prices above competitive levels. In the past, because of the proprietary nature of cost information in most industries, such estimates have relied on concentration measures. Concentration measures, however, suffer from a number of weaknesses, which are exacerbated when applied to restructured electricity markets. This paper has highlighted some of the more important shortcomings, such as reliance on regulation-era market share data and failure to account for either demand elasticities or the costs of different generating plants. Furthermore, the use of data, either historic or derived from simulation, that is based upon an assumption of least-cost dispatch can greatly overstate the geographic scope of markets and therefore the competitiveness of a market.

We have contrasted the approach to market power that relies heavily on concentration measures with the alternative oligopoly equilibrium simulation approach that we, and others, have employed in recent work. This approach takes actual cost, demand, and transmission capacity data into account when employing an oligopoly equilibrium model of the electricity market. In this paper, we have discussed some of the strengths and weaknesses of the market power models that have been applied to the electricity industry. While the Cournot-Nash model we have used is far from perfect – it ignores, for instance, the dynamic aspects of competition – it offers several significant advantages over concentration analyses.

The results of our analysis of two major U.S. regions indicates that during high demand hours, when fringe supply has reached its limit and large players in the market are able strategically to congest transmission lines, market power is indeed a concern. The process of divestiture of generation resources that is currently underway in California appears to significantly reduce the potential for market power in that region. In addition, the results suggest that market power is much more prevalent when demand is modeled as less responsive to price changes.

A number of policy implications emerge from these analyses. Our results indicate that policies that promote the responsiveness of both consumers and producers of electricity to short-run price fluctuations can have a significant effect on reducing the market power problem. In addition, the results suggest that transmission capacity investments may have disproportionate impacts on the price faced by consumers. Indeed, such policies may yield greater benefits, and be less contentious, than other approaches that attempt to regulate prices under various conditions.

The results presented in this paper, although suggestive that the equilibrium prices in a restructured market are likely to diverge from those under a perfectly competitive market, should not be seen as suggesting that deregulation is a mistake. The relevant comparison is not to the efficiency of a perfectly competitive regime, but rather to efficiency under the alternative regulated structure. Similarly, when considering the level of market-power that is ‘tolerable,’ one must weigh the consequences of market power against the costs of intervention in the market.

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