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Math Model Explains High Prices in Electricity Markets

By Sara Robinson

In 1996, in the hope of reducing its historically high electricity prices, California became the first U.S. state to vote to open its energy markets to competition. Following electricity reform efforts in other countries, the state planned to unbundle the different functions of the old regulated monopolies, introducing competition for power generation and retail delivery.

California's venture, however, turned into a disaster of immense proportions, and became the poster child of an anti-power-restructuring movement. Beginning in the summer of 2000 and continuing through the summer of 2001, wholesale power prices soared, forcing the federal government to subsidize power for low-income families in San Diego and bankrupting one of the state's three major utility companies. At the same time, mysterious shortages in available generation capacity forced statewide rolling blackouts. All in all, the energy crisis may have cost the state as much as $45 billion in higher electricity costs, lost business due to blackouts, and a slowdown in economic growth, according to the Public Policy Institute of California.

Following California's vote, several other regions of the U.S.—notably parts of the Northeast and Texas—decided to restructure their power markets as well. While there have been no full-out disasters, these markets, too, have been beset with volatile wholesale prices and other problems.

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The conventional explanation for California's power crisis is that flaws in the restructuring agreement, combined with poor federal oversight, made it possible for companies to artificially drive up prices. Restructured markets that are well designed and well regulated will operate more efficiently than the old monopoly system, most economists say, although most experts agree that U.S. markets, so far, have not realized that promise.

Sean Meyn, an electrical engineer, and In-Koo Cho, an economist, both at the University of Illinois at Urbana–Champaign, are weighing in with an alternative perspective on restructuring. In a recent paper, not yet published, the researchers introduce a dynamic pricing model for decentralized power markets that incorporates some of the unique engineering constraints, such as the slow ramp up of reserve power sources and inelastic supply and demand. From their model, the researchers conclude that restructured power markets (in their current form) are doomed to fail. "The difficulties that have appeared in California and elsewhere are intrinsic to the design of current markets," Meyn says.

Economists interviewed for this article disagree with Cho and Meyn's conclusion about the viability of decentralized power markets, pointing to restructured markets in the UK, Latin America, and, to a lesser extent, Australia as functioning better than the regulated government-owned monopolies that preceded them. "Restructuring has reduced electricity production costs and benefited consumers relative to the former regime in a number of countries around the world, but . . . this has taken a number of years," says Frank Wolak, a professor of economics at Stanford University.

"Every market is imperfect," adds Paul Joskow, a professor of economics and management at the Massachusetts Institute of Technology, "and in many of these markets, the performance before [restructuring] was awful."

The Constraints

Economists and engineers agree that some of the unique physical attributes of electricity make the design of efficient power markets a challenge. (See "The Power Grid: Fertile Ground for Math Research," *SIAM News*, October 2003; http://www.siam.org/siamnews/10-03/powergrid.htm.)

One constraint is that power must be produced as it is needed because of the prohibitively high cost of storing it. Because demand for power is difficult to predict, some power plants are kept on reserve, ready to begin production on short notice. Even so, there is a lag time before additional power can be generated. Because of capacity constraints in power lines and other equipment, it can also be a challenge to deliver electricity where it is needed, when it is needed. A local imbalance of supply and demand, moreover, is not an isolated event: It threatens the stability of the entire regional grid, potentially disrupting all consumers and suppliers. Compounding the problem, consumers are not exposed to real-time prices under the current systems, and thus have no incentive to decrease their power consumption when prices are high.

In this environment, short-term prices for electricity tend to be very volatile, and there are many opportunities for the exercise of market power, notes Severin Borenstein, a professor of business administration and public policy at the University of California at Berkeley, in a paper titled "The Trouble with Electricity Markets: Understanding California's Restructuring Disaster" (*Journal of Economic Perspectives*, Winter 2002).

The California Debacle: How Things Went Wrong

In the late 1990s, despite these challenges, California and other parts of the U.S. moved quickly to restructure their markets. California's Power Exchange opened for trading in March 1998, two years after the vote that set the transition in motion. By then, the state's three major electric utilities had auctioned off most of their fossil fuel-fired power plants. The new owners—energy companies based in Texas and the Southeast, including Duke, AES/Williams, Dynegy, Mirant, and Reliant—were expected to sell power back to the utilities in day-ahead, hourly, and real-time markets. To reimburse the utilities for their "stranded assets"—investments from which they would no longer benefit—the state legislature froze consumer electricity rates through March 2002 at a price thought to be beneficial to the utilities; the freeze was to be lifted sooner if the utilities collected enough to pay off their debts before that date.

To operate new auction-based markets for power, and to manage the transmission grid, the state had created two nonprofit corporations: the California Power Exchange, which would operate the main forward competitive energy markets into which generators would sell electricity, and the California Independent System Operator (CAISO), which was to provide transmission services to all electricity suppliers, moving power to meet demand and imposing transmission charges that would reflect the supply/demand balance in each area of the grid. (The utilities continued to own the lines and were to be compensated for their use.) CAISO was also to manage a real-time market for power, as well as for other ancillary services necessary for maintaining the stability of the grid.

As in markets that had been established in other countries, the wholesale price for power was to be determined by auction. All the generators would submit bids to supply a specified amount of power at a certain price. The Power Exchange would then accept bids, starting with the lowest, until demand was satisfied. The price of the last increment of power needed would then be the price paid to all successful bidders. In the case of an overabundance of available power, with many generators competing to supply it, the price would be low. When demand exceeded available supply, however, generators, no longer at risk of being unable to sell all their power, would have an incentive to bid high.

Ramp-up constraints for power plants, combined with inelastic demand, might make any decentralized approach inherently inefficient, even in the absence of the exercise of market power by participants.

During the first year, there were already signs that market participants were testing their ability to affect prices. On one July afternoon in 1998, for example, the price paid to generators for providing reserve power hit $9999 per megawatt-hour of capacity available, compared with the usual price of about $10. At the same time, market prices for power also soared to record heights. In response, CAISO asked the Federal Energy Regulation Commission to institute price caps of $250 per megawatt-hour, which it did.

The price caps did not prevent other forms of corporate mischief, however. In May 1999, Enron scheduled a shipment of 2900 megawatts of power over a line whose capacity was only 15 megawatts. In the congestion and chaos that followed, prices shot up more than 70% statewide. (Enron was later fined just $25,000 for the incident.) Despite such glitches, the market functioned well for the most part through 1998 and 1999, with wholesale prices hovering around $35 per megawatt-hour.

California's demand for electricity peaks in the summer months, when air conditioners are in use. The state usually counters the increased demand by importing hydropower from the Pacific Northwest. In the summer of 2000, however, hydropower was less abundant than usual because of a drought. At the same time, prices of natural gas and nitrogen oxide pollution permits were unusually high, driving up the operating costs of gas-powered generators.

In an already precarious situation, these events combined to create a perfect storm, with wholesale power prices soaring to levels nearly 500% higher than those of the previous summer. Consumers throughout most of the state were shielded from the price fluctuations, but the utilities were paying as much as $750 per megawatt-hour, ten times the average wholesale rate that was implicit in the fixed retail rate for consumers.

Only the San Diego Gas and Electric Company, which had already recovered its stranded-assets costs and was thus exempt from the rate freeze, was able to raise retail prices. In July, San Diego customers began receiving electric bills two to three times higher than those of previous summers. In response to the ensuing howls of protest, the state stepped in and reimposed the retail caps. Still, the federal government had to use emergency funds to help some residents pay their inflated utility bills.

As winter approached, demand for electricity lessened, but the power shortages and high prices continued unabated. On November 1, 2000, FERC issued a preliminary order concluding that the inflated power prices were "unjust and unreasonable," and thus in violation of the 1935 Federal Power Act that FERC is mandated to uphold. The organization suggested several "remedies" for the situation, including replacement of the $250 per megawatt-hour price cap with a "soft cap" of $150 per megawatt-hour; bids exceeding the cap would be permitted only if generators could show that their costs justified the bids. (FERC also asked the state to raise retail rates and make it easier for the utilities to enter into long-term contracts.) The market surveillance committee, chair-ed by Wolak, responded with a report saying that the suggested remedies would not help and, in fact, were likely to make things worse. The committee noted that the soft price cap would function like no cap at all, because affiliate transactions could be used to inflate a generator's costs, justifying higher bids.

Nonetheless, FERC implemented the soft cap. In January 2001, prices soared to new highs, averaging $290 per megawatt-hour, and chronic shortages of available power forced state-wide rolling blackouts, despite Cali-fornia's relatively low power consumption in January. In response, then Governor Gray Davis declared a state of emergency.

The situation worsened through February and March, and by mid-April, one state utility—Pacific Gas and Electric Company—had declared bankruptcy (even as another independent subsidiary of PG&E's parent company, PG&E Corporation, profited enormously during the crisis from generators it owned), and Southern California Edison teetered on the brink. Finally, the state itself intervened in the market, purchasing long-term power contracts, albeit at inflated rates, on behalf of the utilities. "This was the major factor in stabilizing the wholesale market," Wolak says. Short-ly afterward, FERC extended the soft cap on wholesale power prices across the West.

Economists' Perspective on the Crisis

California's power problems, Wolak suggests in a paper titled "Lessons from the California Electricity Crisis" (*Electricity Journal*, August 2003), stemmed primarily from some critical miscalculations by California's utilities, combined with extremely poor oversight by regulators. In the resulting environment, even a company with a small market share could drive up prices by withholding supply. Starting in the summer of 2000, that ability was enhanced by the diminished competition from hydro-power plants outside the state.

Several groups of economists (that include Borenstein, Joskow, and Wolak) performed studies comparing the actual prices in California's markets with those predicted by models under the same supply/demand conditions. The actual market prices were significantly higher than the models' predictions. At the same time, data indicates that the number of power plants offline for maintenance or emergency repairs was substantially higher than normal. These factors, taken together, are evidence that companies were indeed exercising market power during the crisis, Joskow says.

Market power was a problem because of the utilities' failure to hedge, by purchasing power in advance to be delivered at a future date, Wolak says. Joskow agrees that a lack of forward contracting was a key issue, but puts the blame on the state's regulatory agency, rather than the utilities.

Under the restructuring agreement, all power transactions had to go through the Power Exchange. A generator that had contracted to sell a specified amount at a particular price would still have to bid in the power market for the right to produce that power. Through side payments, the effective payment from the utility to the generator would be the contracted price.

Such a contract reduces a generator's incentive to withhold capacity to inflate prices, Wolak notes, because the generator has already sold the power. Moreover, if the generator bids high in the Power Exchange, it risks losing out in the auction and thus not being allowed to sell its power. In that situation, the generator would have to purchase power at market prices to meet its contract.

Compounding these problems was the failure of regulators to understand the problems plaguing the market and order appropriate remedies. It is this, Wolak believes, that turned market glitches into a full-scale crisis. Regulatory problems are also preventing other electricity markets from delivering on their promise of lower power costs, he says.

Borenstein, in his paper, advocates a combination of long-term contracting and real-time pricing to address the problems in California and elsewhere. In California, retail rates were fixed, and in other U.S. markets, consumers pay a time-averaged price for power or, at best, prices for peak and off-peak times. With exposure to real-time fluctuations in power prices, consumers would have the incentive to conserve during peak times. This would lower the production capacity needed to meet peaks in demand, Borenstein writes, and would reduce prices for long-term contracts. Such measures are not popular, however.

The lack of real-time pricing "is a regulatory failure because it is technologically feasible to do this," Wolak says. "State public utility commissions will not implement retail pricing plans that charge customers according to the hourly wholesale price."

An Engineering Perspective

Without disputing that the issues cited by the economists were in play in the California power crisis, Meyn says he cannot wholly agree with their conclusions. "Why should high prices imply the exercise of market power?" he asks. Such conclusions, Meyn says, are based on intuition obtained from observing gross manipulation by Enron and others, and on decades of analysis of static models.

For Meyn, the fundamental explanation for the problems in California and elsewhere lies in the engineering constraints on power markets. In March 2004, at a workshop on power networks at the Institute for Mathematics and its Applications at the University of Minnesota, Meyn questioned whether a lack of long-term contracts and market manipulation could completely explain the collapse of California's market. He hypothesized that the ramp-up constraints for power plants, combined with inelastic demand, might make any decentralized approach inherently inefficient, even in the absence of the exercise of market power by participants. The static models used by economists to describe electricity markets do not capture ramp-up constraints, he says.

Following the IMA workshop, he and Cho set out to devise a dynamic model that would capture these key physical constraints and yet be simple enough to yield an economic analysis. This spring, Meyn and Cho finally arrived at a model that, Meyn believes, captures the essential features of power markets, albeit in simplified form. They have summarized their results in a working paper titled "Optimization and the Price of Anarchy in a Dynamic Newsboy Model."

The researchers model normalized demand as a driftless Brownian motion that is completely unresponsive to price. The average demand is met through a long-term contract with the primary source, while short-term fluctuations are accommodated by multiple ancillary power sources. All power sources are rate-constrained in their ramp up, with the ancillary power sources ramping up faster than the primary one. Any excess power produced can be dumped at any time without cost, a simplifying assumption that is not true in reality. Ancillary power prices are also assumed to have constant marginal costs as high as, or higher than, that of the primary source—a grossly simplifying assumption, the researchers note, because real costs are nonlinear. There is a high social cost of not meeting demand and incurring a blackout.

Starting from the premise that society benefits from the consumption of electricity, the researchers first solve for a policy that maximizes the total social value: the sum of the profits of the generators and the social value for the consumers. (For readers versed in control theory: This required solving a multidimensional singular control problem.) This policy represents what a centralized controller of a power market would ideally try to achieve.

The theoretical goal for decentralized markets, however, is to optimize through the actions of individuals, without a central controller. Toward this end, the researchers show the existence of an equilibrium price functional for which both consumers and generators arrive at the same policy decisions in a decentralized market. They prove that this equilibrium is unique, and that it coincides with the centralized social optimum. Cho and Meyn go on to show that even when their statistical assumptions on demand are relaxed, an equilibrium price functional, if it exists, must be of the form obtained for the model with Brownian demand.

Remarkably, the prices corresponding to this unique equilibrium are, on average, so high that a consumer would incur a negative benefit from participating in the market. Prices will be volatile even without manipulation, Meyn says, because the unpredictability of demand and the slow response of supply mean there will always be times when demand approaches the available supply and prices soar.

In the model, generators are assumed to be price-takers, meaning that a single generator's actions cannot affect the price. When generators do have market power, however, the basic problem becomes more pronounced, Meyn says. If there is a real-time demand response to high prices, the problem disappears for the most part because demand would approach supply only rarely, Meyn points out. Still, if power reserve levels fall suddenly due to an outage or storm, prices could again explode.

Steven Shreve, an applied mathematician at Carnegie Mellon University, considers the paper "a significant step forward," both for its mathematical contributions and for the issue it raises. The next step for mathematicians, he says, will be to understand all the simplifying assumptions in the model to see if any of them are not justified. "Is this a problem we have to worry about, or is there something in the real market that is different than the model?" he asks.

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