Chapter 9

SURVEY OF ELECTRICITY MODELS FOR CALIFORNIA

Various methods have been used to predict electricity prices in California. Both the CPX and CAISO developed models to predict market prices. Our review begins with an economic analysis of the CPX and CAISO approaches. These methods were developed before the energy crisis. Next, we discuss the econometric approaches that others have used in the various legal/regulatory proceedings that have addressed the question: "What caused the electricity crisis in California?"

THE CPX AND CAISO PRICING MODELS

The CPX adopted a mean-reversion and a vector autoregression models to predict market-clearing prices. The principal authors were Seth Wilson, Robert Earle, and Karen Koyano.[1] We discuss these models in turn.

A Mean-Reversion Model generalizes the Geometric Brownian Motion model that has been used in Black-Scholes options theory.[2] The basic conceptual model is:

[1] See "Review of Price Behavior in the California Power Exchange," Presentation to the CPX Board of Governors, May 18, 2000.

[2] F. Black and M. Scholes, "The Pricing of Options and Corporate Liability," *Journal of Political Economy*, Vol. 81, 1973, pp. 637-659, and R.C. Merton, "Theory of Rational Option Pricing," *Bell Journal of Economics and Management Science*, Vol. 4, Spring 1973, pp. 141-183.

$$\frac{dP}{P} = \mu dt + \sigma dw \tag{1}$$

where P is the price, μ is a constant drift, σ measures price volatility, dP is the change in price in a small time period, dt is the time increment, and dw is a random Weiner process.[3] The random term dw is assumed to be $\varepsilon\sqrt{\Delta t}$, where ε is a standard normal distribution and $\varepsilon\sqrt{\Delta t}$ has a zero mean and a variance equal to Δt. The Geometric Brownian Motion model assumes constant growth μ (per unit time) in prices.

The Mean-Reversion Model modifies these generalizations and assumes that electricity prices revert to an equilibrium level and that in equilibrium there is no drift. Specifically, the Mean-Reversion Model restates equation (1) as:

$$\frac{dP}{P} = \alpha \frac{(L - P)}{P} dt + \sigma dw \tag{2}$$

where L denotes the equilibrium price level. When P exceeds L, there is a negative drift toward equilibrium, and when P falls short of L, there is positive drift. In discrete time, the Mean-Reversion Model is akin to the Koyck model for stock flow investments and has the form:[4]

$$\frac{\Delta P_t}{P_{t-1}} = \alpha \frac{(L_{t-1} - P_{t-1})}{P_{t-1}} \Delta t + \sigma \Delta w_t \qquad \text{or} \tag{3}$$

$$P_t - P_{t-1} = \alpha(L_{t-1} - P_{t-1})\Delta t + (\sigma \Delta w_t)P_{t-1} \tag{3'}$$

The specific version of the model the CPX economists used to estimate prices introduced a stochastic term. The Mean-Reversion Model used by the CPX is a "mixing" model:

[3] A continuous-time random process W(t) with t ≥ 0 such that W(t) – W(0) is normally distributed with mean 0 and variance t - s for 0 ≤ s ≤ t and for which the increments are independent for non-overlapping time periods. I. Karatsas and S. Shreve, *Brownian Motion and Stocastic Calculus,* 2nd ed. (New York: Springer and Verlag, 1997); A. Papoulis, "Wiener-Levy Process," *Probability, Random Variables, and Stocastic Processes,* 2nd ed.(New York: McGraw-Hill, 1984), pp. 292-293.

[4] L.M. Koyck, *Distributed Lags and Investment Analysis* (Amsterdam: North-Holland Publishing Company, 1954). See also M. Nerlove, "Distributed Lags and Demand Analysis," U.*S. Department of Agriculture Handbook 141*, Washington, D.C., 1958.

$$\frac{dP}{P} = \alpha(\frac{L - P}{P})dt + \sigma dw + dg \qquad (4)$$

where dg is a second stochastic term. The additional term acts as a random jump that is specified to be independent of dw.

Mean-reversion models are known in the finance literature as Vasicek models.[5] Relatively simple formulas for the prices at European put and call options exist under mean-reversion and are discussed in Hull and White.[6]

The CPX specific model is estimated using a moving-average of past prices as an estimate of the equilibrium level L. Thus, the CPX model is completely identified by the historical time-pattern of prices. The CPX model is, consequently, not structural because it does not rely on the behavior or character of the economic market in which prices are set. Put simply, past prices predict current prices. The model does not explain why the equilibrium price level changes. Therefore, the model cannot detect why market prices surge or test the sensitivity of various economic factors. The deficiency in the mean-reversion model in explaining causal effects can be addressed by integrating it into a setting that explicitly determines structural effects. In this approach, the equilibrium price level L is specified to be a function of economic factors. This, in effect, is the approach we adopt in our econometric analyses of electricity prices in California.

The second CPX model is known as a Vector Auto-Regression Model (VAR). The CPX's VAR model estimates prices in the CPX's day-ahead market (unconstrained market clearing prices or UMCPs) using the previous day's price in the day-ahead market; the CAISO load forecast; natural gas prices for PG&E, SCE, and SDG&E city gates; temperature at San Francisco, Sacramento, Los Angeles, and San Diego; coal plant availability of the three IOUs; and nuclear availability of the three IOUs.

The CPX VAR model was estimated using data for 731 days from April 1, 1998 through March 31, 2000. To avoid extreme multicollinearity, the explanatory variables are reduced to lower dimensional subsets using principal component analysis. In the PX VAR model, there are 58 parameters estimated: six each for load and squared load, two for unit availability, three for gas prices, eight for temperature, four interactions between gas prices and temperatures and 28 parameters for lags of UMCPs. The model has an auto-regression correction, which requires maximum likelihood estimation.

[5] Vasicek, "An Equilibrium Characterization of the Term Structure," *Journal of Financial Economics*, Vol. 5, 1977, pp. 177-188.

[6] John Hull and Alan White, "Pricing Interest-Rate-Derivative Securities," *The Review of Financial Studies*, Vol. 3, 1990, pp. 573-592.

The CPX used VAR models that were reduced-form and non-structural. Therefore, the CPX model mixed together supply and demand explanatory factors without any attempt to identify supply or demand.

Commodity markets, such as the wholesale electricity markets in California, have buyers and sellers who bid in an auction. As we discussed earlier, there was a single price auction for the CPX. Market factors inform both sellers and buyers. The quantity demanded matters, but factors such as weather, economic conditions, and natural gas prices are generally more important because such information can inform *ex ante* bids.

Quantity effects can be ambiguous. It is quite possible, and in California commonplace, for market clearing bid prices to be relatively high during low demand months, as well as during off-peak periods in low demand months (*e.g.*, winter). Similarly, prices could be low during high demand months and during peak periods in the high demand months (*e.g.*, summer). The CPX focused on market clearing price predictions and the underlying factors that may have influenced bidding behavior in the wholesale electricity market. Others that followed have generally followed this approach and, as a result, the quantity sold at any given point in time has generally been relegated to a secondary status.

We now turn to the CAISO specific models. The CAISO approach employed engineering estimates of the incremental cost of supplying electricity. The concept behind this approach is that in competitive markets, sellers are price takers and would bid their short-run or incremental generating costs. As we explain below, the FERC adopted this conceptual approach for this reason in determining the Mitigated Market Clearing Price (MMCP), in the California Refund proceedings.[7]

The CAISO model simulates competitive market clearing prices using engineering estimates of incremental cost, which are then compared to actual market clearing prices. Wolfram (1998),[8] Wolak and Patrick (2001),[9] and Wolak (1999)[10] adopted similar approaches. The CAISO approach adopts a competitive price benchmark standard that is estimated according to

[7] *San Diego Gas & Electric v. Sellers of Energy and Ancillary Service Into the Markets Operated by the California Independent System Operator and California Power Exchange,* Docket Numbers EL00-95-075 and EL00-98-063.

[8] C. Wolfram, "Strategic Bidding in a Multi-Unit Auction: An Empirical Analysis of Bids to Supply Electricity in England and Wales," *RAND Journal of Economics* 29 (1998): pp. 703-725.

[9] R. Patrick and F. Wolak, "Estimating the Customer-Level Demand for Electricity Under Real-Time Market Prices," *NBER Working Paper No. 8213*, April 2001.

[10] F. Wolak, "Market Design and Price Behavior in Restructured Electricity Markets: An International Comparison," Stanford University Department of Economics.

engineering supply curves measured at the point of residual demand. Borenstein, Bushnell, and Wolak (2000)[11] applied a similar methodology.

The objective of these approaches was to measure market power through the mark-up of price relative to marginal cost. This work was conducted for the CAISO's Market Monitoring Committee, which defined market power in the Lerner sense as: "the ability of a firm, through its input or pricing decision, profitably to raise the market price above the competitive level."[12] The degree of market power is based on the gap between actual prices in comparison to engineering estimates of marginal costs.

Similar pricing models discussed in the literature include Borenstein, Bushnell, and Knittel (1999)[13] and Borenstein and Bushnell (1999)[14]. These both rely on a constant benchmark price using residual demand and engineering estimates of marginal cost.

Other market power studies in the literature include Joskow and Kahn (2001),[15] who also rely on a competitive price benchmark estimated by engineering methods, and Wolfram (1999),[16] who relies on a price-mark-up calculation with observed price and estimated marginal cost. This study differs from those previously described because it relies on the demand curve to calculate an elasticity adjusted price cost mark-up consistent with the Lerner mark-up.

The CAISO-based models are not econometric models. They do not attempt to estimate electricity prices using econometric methods. Instead, the CAISO models used engineering estimates to derive marginal cost. These models estimate the degree of market power using price mark-ups above marginal cost. However, these market power models cannot distinguish the various causes of the differences between price and short-run marginal cost

[11] S. Borenstein, J. Bushnell and F. Wolak, "Diagnosing Market Power in California's Restructured Wholesale Electricity Market," University of California Energy Institute, August 2000.

[12] J. Bushnell, A. Klevorick, and R. Wilmouth, "Third Report on Market Issues in the California Power Exchange Energy Markets: The Impact of Reliable Must-Run Contract Reform and Ancillary-Services Market Redesign on the Performance of California's Electricity Markets." Prepared by the Market Monitoring Committee of the California Power Exchange on behalf of FERC, June 2000.

[13] S. Borenstein, J. Bushnell, and C. Knittel, "Market Power in Electricity Markets: Beyond Concentration Measures," University of California Energy Institute, February 1999.

[14] S. Borenstein, and J. Bushnell, "An Empirical Analysis of the Potential for Market Power in California's Electricity Industry," *Journal of Industrial Economics* 47, September 1999, pp. 285-323.

[15] Paul L. Joskow and Edward Kahn, "A Quantitative Analysis of Pricing Behavior in California's Wholesale Electricity Market During Summer 2000," AEI-Brookings Joint Center Working Paper No. 01-1, January 2001.

[16] C. Wolfram, "Measuring Duopoly Power in the British Electricity Spot Market," *American Economic Review* 89, 1999, pp. 805-826.

such as market power abuse, strategic bidding, or economic rent due to other market and structural problems.

OTHER ECONOMETRIC MODELS

The California electricity crisis caused the FERC to consider refunds. The general premise of the various refund proceedings is that competitive markets are "just and reasonable" because sellers in competitive markets would bid their short-run marginal cost (SRMC). Consequently, economic rent would be paid to infra-marginal suppliers when the single MCP was greater than their short-run marginal cost of production. Consider Figure 9-1.

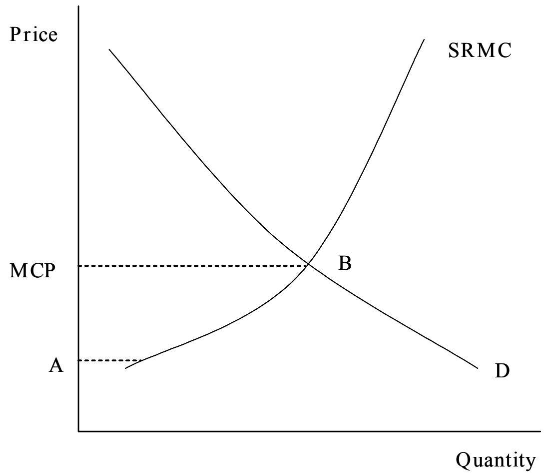

Figure 9-1. Short-Run Marginal Cost

Sellers that operate between A and B have lower SRMC than the MCP. These sellers collect a mark-up over SRMC that pays down fixed and other risk-related components of their generation activity.

The CAISO and FERC's modeling approach, which focus on MMCP, are fully consistent with the proposition that MCPs for competitive markets would reflect SRMC. The difficulty that is masked in Figure 9-1 is that demand and supply curves shift in response to market forces and input prices. Therefore, various parties in the California refund proceedings have attempted to test various hypotheses to determine the factors that caused market prices to vary in California before, during, and after the refund period.

Table 9-1 summarizes these various studies. The analyses of Harvey and Hogan are very similar to the analyses we perform. Daily electricity prices are analyzed and adjustments are made for serial correlation. The econometric analyses in Chapter 11 does both these things.

Table 9-1. Quantitative Analyses Relevant to the California Energy Crisis

Author/ Document	Analysis	Factors	Results
Scott Harvey and William Hogan's testimony on behalf of Morgan Stanley, Mirant, AEP, and Reliant	Price correlations of daily prices mid-2000-late 2001 using OLS regressions.	Dependent Variables: Various NYMEX forward strip prices. Independent Variables: Various spot prices.	There was a high correlation between forward and spot prices. However, there was a significant presence of serial correlation in the models.
	Price correlations of daily prices mid-2000-late-2002 relying on Prais-Winsten regressions to adjust for serial correlation.	Dependent Variables: Various NYMEX forward strip prices. Independent Variables: Various spot prices.	When the models were corrected for serial correlation, there was a drastically weaker statistical relationship between spot and forward prices.
Scott Harvey and William Hogan's LECG Report sponsored by Mirant	Discusses the shortcomings of the Joskow-Kahn market simulation in estimating prices and determining the presence of market power using daily data of 13 generators with relatively high heat rates, for June 2000.	Klein full load capacity, Klein full load incremental heat rate, gas price, emissions price.	Simulation of market dynamics showed that on several days in June, it would have been unprofitable for certain generators to operate even during peak demand hours due to minimum load costs and unit inflexibilities.
Seth Wilson, Robert Earle, and Karen Koyano's presentation entitled "Review of Price Behavior in the PX"	Monitor the market for price spikes and volatility from 4/1/98 to 3/31/00 using a mean reversion model.	Dependent Variables: Change in Price. Independent Variables: real-time and day-ahead prices, present and lagged values.	Means are based upon moving averages of past prices, producing and estimated equilibrium price. Market prices revert back to equilibrium levels in less than two days. Real-time prices are much more volatile than day ahead.
	Measure congestion and location risks of prices from 4/1/98 to 3/31/00 by calculating correlation coefficients.	Day-ahead prices: UMCP, NP-15 and SP-15. Real-time prices: SP-15 and NP-15.	Comparing the periods Apr98-Mar99 and Apr99-Mar00, correlation of NP-15 with SP-15 and NP-15 with UMCP is much lower in the second year.
	Determine if changes in the UMCP from 4/1/98 to 3/31/00 are attributable to market fundamentals using a Vector autoregression with 24 lagged values.	Dependent: Hourly UMCP, Independent: load forecast lagged 1-24), load forecast ^ 2 (lagged 1-24), unit availability, lag temps, lag gas prices, interactions, UMCQ (lagged 1-24), UMCP (lagged 1-24).	In most hours, 80% of variation in the UMCP can be explained by market forces and auto- and cross- correlations. Actual UMCPs show an increasing trend in prices during the time period. When prices are adjusted for market fundamentals, the trends are no longer present.
	Determine demand responsiveness in PX day-ahead market from 4/1/98 to 3/31/00 by calculating price elasticities.	Day-ahead prices.	The absolute price elasticity is greater than 1 during 27% of the time period.
Miles Bidwell's testimony on behalf of the City of Tacoma and Port of Seattle	Show Reliant's sensitivity in profits if market clearing prices for June 2000 and June 2001 were 50% and 100% greater than marginal costs. Account for changes in gas prices and NOx rates. Demonstrate that Reliant would still earn profit if the market price was set equal to the marginal cost of the most expensive unit in Reliant's portfolio.	Gas prices and NOx rates. Heat rates and capacity.	A 50% increase in market price over marginal cost would double Reliant's net revenue. Increasing gas and NOx prices from $5 to $10 would also double Reliant's revenue.
Robert McCullough's testimony on behalf of the City of Tacoma and Port of Seattle	Perform a Monte Carlo simulation calculating the likelihood that the actual availability of CA power plants was consistent with the availability percentages reported in the Generation Availability Data System (GADS) using data of available capacity for power plants during 2000 and 2001.	Available generating capacity per plant, total generating capacity for all plants.	Actual available capacity was disproportionately lower than simulated available capacity during emergency days.

The CPX models constructed by Seth Wilson *et al.* were not prepared to test hypotheses concerning what caused fluctuations in California electricity prices. They do, however, support the idea that reduced form models with price as the dependent variable should be used to test hypotheses related to what factors affected the MCP in California.

Miles Bidwell's analysis is company specific and focuses on the degree of price mark-ups over marginal cost. It is a specific application of the CAISO modeling that was designed to test for the presence of market power.

Mr. McCullough's model is unique. He analyzes plant availability and outages and determines that 2000/2001 had excessive outages. He also has filed written testimony where he alleges that the significance of the drought in 2000/2001 is overstated. Mr. McCullough's approach has had many critics. We will not repeat that here. Instead, we present his work in Table 9-1 for completeness. It has had little effect on what we did because our approach was concerned with prices, not plant availability.

We next describe our econometric analysis of natural gas prices during the California electricity crisis.