Forecasting Long-term Electric Price Volatility for Valuation of Real Power Options

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Abstract
In a competitive market, wholesale electricity prices drive the value of generating assets, wholesale contracts, and retail commitments. Forward prices for power unambiguously set the current value of these assets, but as in most commodity markets these prices exhibit extreme volatility. Understanding this price volatility helps quantify the risks of market participation, but also is critical to valuing options conditional on those prices. When these volatilities are unknown due to thin forward markets and a lack of price history, forecasting them accurately has great business value. This paper outlines a structural approach to estimating market volatility and demonstrates its application to valuing a real option, in this case a gas-fired peaking generating unit.

1. Introduction
State-of-the-art long-term market price forecasts help market participants take advantage of the tremendous profit opportunities associated with decisions to build, buy, sell, or retire power plants; undertake long-term bulk power transactions; and lock in retail and wholesale customers with fixed prices for extended periods. Such forecasts also aid in quantifying the risks inherent in such decisions and assessing the value of strategic and operational flexibility and of recognizing the option value of many of these decisions.

Corporate organizations with strong analytical capabilities directed at price forecasting that have integrated analysis into their decision making will be better at finding the opportunities and dodging their risks. Corporate capability to estimate quickly (and update with new information) forward prices, volatilities, and correlations is a strategic asset of immense value.

Over the last four years EPRI and its members, working with The NorthBridge Group, have invested close to $2 million in developing and testing a state-of-the-art methodology to forecast electricity prices in a competitive power market. The method applies Wall Street "savvy" (i.e., modern finance theory for valuation) with power system economics. The results are option valuation techniques adapted to the unique features of competitive electric power markets. Nineteen U.S. and international electricity companies are working with EPRI to use this approach to prepare themselves for and operate successfully in these markets.

This article outlines the reasons why forward power price forecasting is important but difficult, provides an overview of a structural approach to forecasting forward prices and volatilities, and demonstrates the application of the approach to valuing a real power option, in this case a gas-fired generating unit that can be dispatched on an hourly basis.

2. Valuation with forward prices
Valuation in competitive markets depends on the net cash flows, which are based on highly uncertain spot prices. While spot prices rise and fall in daily markets and forecasts of them are uncertain, the existence of forward prices in some markets removes this uncertainty at any point in time and allows risk-neutral valuation of assets. Forward prices are settled in advance of delivery, e.g., agreed on today for payment and delivery next month. Setting the prices in advance allows risk neutral valuation in that no adjustment to the value is needed to cover the risks from spot price uncertainty. Risk neutral cash flows have the advantage that they can be valued over time with a "risk-free" discount rate.

Forward prices are used to value assets in commodity markets, and the principles apply directly to newly emerging markets, such as electric power. However, in power markets forward prices are often lacking or do not trade far enough in the future to be useful for valuation. Analysts assessing the value of electric power assets are forced to forecast forward prices themselves as a foundation for decision making.

Two issues particularly challenge analysts when forecasting forward prices: 1) developing price forecasts that are the financial equivalent of forward prices suitable for risk-neutral valuation, and 2) representing uncertainty
to both “qualify” the forecast and help estimate the value of assets that behave like financial options.

3. Why forward prices are useful

With any price forecast it is necessary to make the distinction between spot and forward prices and the corresponding distinction between risk-adjusted and risk-free discount rates in discounting cash flows to get present values. The mis-combination of different kinds of prices and discount rates can create confusion leading to mistakes worth millions of dollars in excessive bids for power plants, failed independent generator buyouts, and lost wholesale contracts.

In general, future cash flows that are certain (involve no price risk), such as a signed forward contract, should be discounted at a risk-free rate equivalent to Treasury securities. The resulting stream of cash payments can be replicated by purchasing a portfolio of Treasury securities. The cost of buying those securities is equal to the value of the certain payments. Thus, the rate of return on the Treasury securities (e.g., 6%) provides a risk-free rate that can be used to obtain the present value of future cash flows that are certain.

Future cash flows from the sale of a commodity with a future price that is uncertain require a risk adjustment or discounting at a higher rate to cover the risks. Financial markets, reflecting a “market price on risk,” discount uncertain cash flows more heavily than certain ones. Market valuation of an uncertain stream of payments requires that payments be discounted at a rate above the risk-free rate (e.g., 15%). The discount rate that makes investors indifferent between the certain cash flows and the uncertain stream of cash flows is called the risk-adjusted rate.

We present the relationship between forward prices and forecasts of spot prices in Figure 1. The gap between expected (forecasted) spot and the forward price represents the risk premium for spot price uncertainty.

Figure 1 shows how forward prices (which are certain at any point in time) will generally be consistently lower than forecasted spot prices (which by nature are uncertain). Risk-adjusted discounting of uncertain spot price cash flows produces expected value forecasts for spot prices that are biased (upwards) estimates of forward prices. The difference between the two forecasts is a risk premium for spot price uncertainty. For forecasters, who typically are working in a spot price world, this means that users of their forecasts must use risk-adjusted discount rates on the forecast results, or that the users should adjust their forecasts by the appropriate risk premium so they are financially equivalent to forward prices.

Unfortunately, these risk premiums are very hard to deduce for a complex commodity such as electric power. The premiums are not observable, and differ depending on the nature (volatility) of the products. For example, summer peak power, summer off-peak power, and winter monthly power are distinct products that will have different volatilities and corresponding risk premiums. For electricity prices, the expected cash flows from a predictable baseload unit might be discounted at 12% while the flows determining the value of a irregularly used peaking unit might be discounted at 20%. So, analysts who rely only on spot price forecasts without risk-adjusted discount rates will have a systematic bias toward overvaluing assets with risky cash flows. In practice, we have found that it is easier to estimate the financial equivalent of forward prices and use a risk free discount rate than to estimate and apply risk-adjusted discount rates that vary by hour, day and season.

3. Measuring uncertainty in forward prices

Uncertainty is inherent. In developing “financially equivalent forward electricity prices” for valuation, it is critical to recognize that forward prices are inherently uncertain over time due to uncertainty in weather, equipment outages, fuel prices and other price drivers. This uncertainty applies to all markets; while we can see the market’s closing forward price curve for crude oil in the newspaper, we can also be reasonably sure the curve will be different in tomorrow’s paper. Forward prices change as new information becomes available, so any forecast is doomed to be obsolete once new information comes to market.

The “fact” of uncertainty (new information) does not obviate the usefulness of forecasts, however. It means that analysts need to complement their price forecasts with forecasts of the uncertainty as well. Representing the uncertainty “qualifies” the forecast, so the user can...
Values of real options depend on the degree of uncertainty. The more direct benefit for estimating the level of uncertainty is that uncertainty itself can be a source of value for assets with optionality. This is because the potential for price changes is the key driver of the value of options, which confer the right to cash in on large price swings. An example would be an option to buy power at $30/MWh (this option would be economically equivalent to owning a coal unit that can generate power at $30/MWh). If prices are currently $23/MWh, neither the option nor the plant has immediate value. However, both do have potential value if there is a chance prices will rise above $30. The more uncertain the price, and the greater the potential price swings, the greater potential profit if those extreme prices occur. Valuations of such an asset that does not include this real option value will under-represent the potential value of the asset.

Volatility measures the time rate of uncertainty. Modeling price uncertainty for stock prices uses the concept of volatility. The classic price model that people use in financial markets is:

$$\text{dP} = \alpha \text{P dt} + \sigma \text{P dz}$$

The change in price (dP) is a function of the drift ($\alpha$) and the volatility ($\sigma$). The drift is multiplied by dt (a small change in time), and represents the trend in prices. The volatility is multiplied by dz (a random variable, also called a factor) to characterize the price changes. This model is often called a “random walk” model because the dz provides random “kicks” to the price (up or down) during each dt, while the volatility determines how far those kicks actually move price. The volatility can be thought of as a rate of price uncertainty. The further out in time (over which the dz’s accumulate), the greater the price uncertainty.

Estimating volatility is more work for the forecaster, but despite the difficulty, volatility has become central to thinking (and acting) in equities markets and in organized commodity markets. Getting volatility estimates right is important. If analysts over-estimate the volatility—which is easy to do if they confuse cyclical behavior for uncertainty, or neglect “mean reversion”—the high estimate of volatility will lead to over-valuation of the option.

Unfortunately, volatility is a new concept for power market analysts, and a much more difficult concept to apply to electric power. Three factors conspire to make the analyst’s job more difficult: mean reversion, prices are cyclic, and the need for temporal detail.

Mean reversion. Traditionally, electricity companies have used best-guess forecast and sensitivity scenarios to acknowledge uncertainty. But these sensitivity scenarios would typically be all high, or all low, cases. This all high or all low structure produces extreme valuation ranges that can be so broad as to be irrelevant. In real life, prices may rise to the upper bounds, or fall to the lower bounds but they do not stay at the limits for long. Instead they tend to wander up and down along a central pathway.

Understanding the phenomenon of mean reversion is complicated but necessary for the representation of uncertainty for commodities and electric power. Commodity prices jump around day to day, sometimes as much or more than stock prices, but over time they tend to stay within a band dictated by “fundamental” supply and demand considerations. If soybean prices rise, that gives growers an incentive to plant more soybeans, which drives the price down. Similarly, if prices are “too low,” farmers will shift production to other crops, supply will diminish, and prices will rise.

The same logic applies to power prices. This implies that volatility, estimated from day-to-day price change, will over-state how much prices are likely to change over longer periods. A volatility “term structure” is needed to capture the effect of high near-term volatility with lower volatility for more distant time frames. Capturing mean reversion requires more analysis of data and more complicated analytical models, but is familiar to commodity market analysts.

Electricity prices follow predictable cycles. A second complicating factor that is unique to electric power is that the basic commodity is a flow in which instantaneous delivery and prices vary wildly over daily, weekly, and seasonal cycles. Looking at the past, analysts must separate out the variation due to “predictable” cyclical factors from variation due to uncertain price drivers. In building a forecast, analysts must be able to reassemble the cyclical and the uncertain components to get meaningful price behavior.

Temporal detail matters. Still further complicating the price forecasting problem for electric power price analysts is the need to preserve a very high level of temporal detail. Hourly chronological resolution is needed to value typical products such as 5x16’s (i.e., power traded by the peak 16 hours, typically 6am to 10pm, of the 5 weekdays) . Related is the need to value products with different aggregations over time. Because of mean reversion, the uncertainty in a daily price will be...
much greater than the uncertainty in a monthly product that averages daily prices.

Also driving the need for temporal detail is the phenomena of price spikes. Prices might average $30.00, but in a crisis hourly or even daily prices can rise to hundreds or even thousands of dollars per MWH. These few hours can contribute a significant fraction of the average price and the bulk of the value to a dispatchable power plant. Modeling prices on a monthly basis does not capture this within-the-month phenomenon and does not estimate the full value.

Volatility is not the only attribute that is critical. Correlations between power prices and fuel market prices are needed to value generating assets that rely on a “spark spread” between fuel and power prices. All the complexities of estimating mean reverting volatility are multiplied for estimating these correlations.

Addressing these forecasting challenges is a difficult job. For valuation of power, what analysts ultimately need are forecasts of hourly prices, their volatilities and correlations with fuels, for each hour, and reflecting mean reversion. This raw material can then be used to build up price forecasts, volatility and correlations for almost any product or asset.

5. The stakes are huge

For a power plant that operates 5,000 hours per year, a $1 change in the forward price leads to a $5 million change in revenue per year. Assuming the change is independent of fuel prices, valuing this flow as an annuity at 5% implies a present value of $100 million. Similarly, not appreciating option value can lead to missed opportunities, while over-estimation of volatilities (e.g., ignoring mean reversion) can lead to over-valuations in the hundreds of millions.

Profit opportunities are greatest in new markets where the uncertainty is high. Unfortunately, so are the risks. When the uncertainty is greatest, analysis has the greatest payoff. Corporate organizations with strong analytical capabilities directed at price forecasting that have integrated analysis into their decision making will be better at finding the opportunities and dodging their risks. In a rough and tumble world, corporate capability to estimate (and update with new information) forward prices, volatilities, and correlations is a strategic asset of immense value.

6. Methods for forward price forecasting

Over the last four years, EPRI’s Power Markets and Resource Management (PM&RM) area, working with The NorthBridge Group and numerous electricity companies, has been developing methods to estimate forward prices, volatilities, and correlations in electric power markets. The goal of this effort has been to give EPRI’s investors a competitive edge in valuing electric power assets. Given the complexities discussed above, and many others not discussed here, this has been quite a challenge. Approximately $2 million has been spent working with a large group of electricity companies to develop methods that are helping them cash in on uncertainty and profit opportunities of competitive electricity markets. The intellectual effort has been led by Tom Parkinson of The NorthBridge Group with strong analytical participation by Richard Goldberg, formerly at EPRI and now with The Brattle Group.

The goal of this development effort has been to invent the state-of-the-art for forward price forecasting for electric power. A driving objective has been to maintain consistency with modern finance theory needed for risk-neutral valuation of forward deliveries and real options. This has meant paying particular attention to the distinction between spot and forward prices, and to development of volatilities and correlations. At the same time, the development effort has striven to recognize the unique aspect of electric power markets that make applications of estimation methods from other commodity markets problematic. These differences include the cyclical behavior of prices, high volatility with high mean reversion, and the strong relationships to fuel markets.

The development has not occurred in a vacuum. A key concern in the development process has been communication. This was accomplished by independent application by the electricity companies in application case studies or collaborative efforts (“collaboratives.”) in which groups of electricity companies have worked with EPRI and NorthBridge to apply the methodology on their own through group case studies. Analyses have been completed, or are ongoing, with 17 U.S. electricity companies and two international electricity companies.

A detailed report—Forward Price Forecasting for Power Market Valuation (EPRI TR-111860 and a series of technical briefs help to document the methodology. The methodology is outlined in Figure 2.
Figure 2. EPRI-NorthBridge forward price forecasting process

The core of the methodology is a multi-step process. Much of the effort and skill are front-loaded in the first three steps: developing the input data, adjusting the data to reflect a consistent representation of market risk, and designing scenarios to represent the uncertainty in the future. In these steps the user is estimating the behavior of key inputs in terms of price process models. Most have to be estimated or inferred from raw data.

Risk adjustment of the inputs is critical to development of risk-neutral expected spot prices that are the financial equivalent of forwards. The EPRI-NorthBridge process treats electricity as a derivative product based on the inputs to the market model. If the price of power is derived from inputs that are risk-neutral (priced as forwards), then it will be a risk-neutral price (or a forward equivalent price) as well.

The fourth step, regional market modeling, can be filled by any number of publicly available models or in-house regional models. What is needed from this step are good estimates of spot prices over the study time horizon and across the input scenarios generated in step three. However, speed is essential. In some of the company case studies, models that were too slow to cover the scenarios in a few hours greatly impeded analysts efforts to benchmark and test the system with their data. One model that has worked well, however, has been MIDAS, which is fast and has good data-handling capability.

In the final steps, statistical analysis of the risk-neutral spot price results is applied to estimate the forward prices, volatilities, and price correlations across commodities. These can then be used to value generating plants, retail contracts, or other assets. Another approach is to evaluate the asset against the price scenarios generated by the market model. In either case, it is critical to keep in mind that the results of the EPRI-NorthBridge process are unbiased estimates of true forward prices, not spot prices that require further risk adjustment. As such they are the best possible substitute in the absence of an actual market that sets prices for forward deliveries.

Supporting the parameter estimation process in step 1 are a number of spreadsheets designed to analyze data and fit parameters. These spreadsheets sift the data on fuel prices and other inputs to characterize two or three factor (the “dz” in the price process equation presented above) mean reverting price processes. In essence, we are superimposing two or three random walk models on top of each other to better mimic real-world behavior. However, a high level of understanding is needed to use these tools, and few analysts have experience fitting multi-factor mean reverting processes with real-world
data. For this reason, applying the methodology takes significant training and personal support. While the methods are documented in EPRI reports, the practice has been that users learn the art of application in hands-on collaboratives with coaching from the developers.

The latest product is an integrated forecasting system, FastForward, which brings together the Scenario Generation, Market Model, and Statistical Estimation steps in one integrated package. The product is hourly forecasts of power prices and their associated volatilities. As this system produces results very quickly, it encourages the user familiar with the methodology to experiment with alternative parameter formulations and promotes understanding of the general process for price estimation. Even if the user prefers a more detailed market model, the speed of the FastForward system means it is probably still useful to use FastForward to do most of the preliminary analysis, testing, and calibration runs before running the more detailed model.

7. Forecasting forward prices and volatilities

To demonstrate some of the forecasting issues discussed here and the application of the EPRI-NorthBridge methodology we conducted a 10-year forecast based on illustrative but realistic data. Example results for a FastForward run were pasted into Excel and plotted for the Figures 3, 4 and 5 below. The results are illustrative of the concepts discussed here and are not intended to make any general prognostications on prices, volatilities or power plant values. What these results do show is the feasibility of the approach and the general pattern of the results.

![Forward Price Curves ($/MWH)](image)

**Figure 3. Sample forward price curves**

The forward price curves in Figure 3 describe monthly peak and off-peak power typically traded in the U.S. The peak product covers the peak 16 hours of weekdays while the off-peak product refers to the remaining hours in the month. The values are aggregated across the hours of the month and over the multiple scenarios evaluated to produce simple averages for those hours. Of course, the results of hourly scenarios can be aggregated to estimate the prices of a great variety of other products.
Figure 4. Sample volatility term structure

The volatility plots in Figure 4 correspond to the product definitions demonstrated in Figure 3. It shows higher volatility for peak product and the rapid decline in both the peak and off-peak products consistent with mean reversion. It is also clear from the figure that volatility has a strong seasonal component with higher values observed during the peak seasons. In the EPRI-NorthBridge methodology, these volatilities are derived from the variance of the product prices across the scenario prices generated by the market model (step 4) and the time to delivery.

8. Estimating the value of a real option

The uncertainty in power prices leads to uncertainty in the returns to owners of generating units. To demonstrate the calculation of the value of a real option, we applied the results from the illustrative example to estimate the net cash flows for a gas-fired generating unit.

The power plant behaves like a real option in that it can be dispatched on an hourly basis throughout the 10-year period. Its value is equivalent to a portfolio of hourly options, equal in quantity to its generating capability. The strike price for these options is equal to the sum of fuel and variable operating costs of generating per MWh. For each hour that prices are above this threshold, the unit runs and the net cash flow for that hour is the difference between the price of power and the operating costs. If the price is below this value, the unit does not run.

The value of the unit is the present value of these cash flows over the analysis period plus the remaining value of the unit at the end of the analysis period. If the market price for each hour is a financially equivalent to a forward price, then the cash flows can be discounted at a risk-free rate (e.g., 6%).

In Figure 5, we plot the cumulative distribution for the present values of returns to ownership of the gas-fired power plant over the 10 year period. These returns are defined as revenues minus fuel costs and annual fixed maintenance costs, but do not include debt payments or expected returns to owners.
Figure 5. Sample power plant valuation

This example was created by evaluating the generating unit against the 30 hourly price scenarios that were used to develop the forward prices and volatilities presented in Figures 3 and 4. The 30 hourly scenarios were ranked from lowest to highest and given a probability of 3.33% to create the cumulative distribution in Figure 5.

The trajectories of daily gas prices and hourly power prices differ greatly from scenario to scenario. The expected value of this distribution is $55,000, but the figure shows the returns to be highly variable across the scenarios. On the low side, the distribution shows some probability (~12%) of negative returns over the 10 year period, while on the up side it shows a 20% chance returns will exceed $73,000/MW. With this distributional information investors have a good representation of the risks they are facing and the corresponding value of locking in prices with long-term contracts.

One of the advantages of this scenario approach is that the hourly detail in the scenarios can be used to assess operational limitations such as minimum run times for the unit. For example, if the unit can only run in three hour blocks, the scenario detail allows the analyst to compare the three-hour rolling price average needed to assess the cash flows.

9. Summary

The values at stake in newly deregulated markets are immense. Although prices for the future are highly uncertain, this uncertainty gives value to assets that have optionality. The greater the uncertainty the greater the opportunity for extreme price regimes to occur that will provide cash flows to the option. Good representation of future power prices, and their uncertainty, is very challenging, but the benefits can be worth hundreds of millions of dollars.