Cross Hedging and Value at Risk: Wholesale Electricity Forward Contracts

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Chi-Keung Woo, Ira Horowitz,* and Khoa Hoang

Energy and Environmental Economics, Inc.

* Horowitz is Graduate Research Professor Emeritus in the Warrington College of Business at the University of Florida.

Address correspondence to:

Dr. Chi-Keung Woo
Energy and Environmental Economics, Inc.
353 Sacramento Street, Suite 1700
San Francisco, CA 94111

Phone: (415) 391-5100
Fax: (415) 391-6500
E-Mail: ck@ethree.com

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Abstract. We consider the problem of an electric-power marketer offering a fixed-price forward contract to provide electricity purchased from a fledgling spot electricity market that is unpredictable and potentially volatile. Using a spot-price relationship between two wholesale electricity markets, we show how the marketer may hedge against the spot-price volatility, determine a forward price, assess the probability of making an *ex post* profit, compute the contract's expected profit, and calculate the contract's value at risk. Such information is useful to the marketer's decision making. The empirical evidence from highly volatile spot-price data supports our contention that the spot-price relationship is not spurious and can be used for the purpose of risk hedging, pricing, and risk assessment.

1. Introduction

Recent regulatory reforms at the federal level have led to a profound restructuring of the U.S. electric power industry (Joskow, 1997; Woo *et al*., 1997). The passage of the 1978 Public Utilities Regulatory Policy Act sparked the early development of a competitive power-generation industry. The 1992 Energy Policy Act gives the Federal Energy Regulatory Commission (FERC) broad power to mandate open and comparable access to transmission owned by electric utilities. In 1996, the FERC issued Orders 888 and 889 that specify the terms and conditions and the *pro forma* tariff for transmission open access. These reforms foster the development of competitive wholesale electricity markets at major delivery points of the high-voltage transmission grids in the U.S.

Wholesale electricity trading has grown exponentially, dominated by power marketers not affiliated with electric utilities (Seiple, 1996). In addition to spot-market trading, a power marketer may offer fixed-price forward contracts to wholesale buyers such as electric utilities that resell the electricity to their retail customers. Because a forward contract obligates the marketer to deliver electricity at a specific location, it exposes the marketer to volatile spot electricity prices at the market in that location. Such exposure is self-evident when the marketer does not own generation and must make spot-market purchases to meet the delivery obligation. Even when the marketer owns generation, however, the electricity generated has an opportunity cost equal to the spot price. Thus, spot-price volatility, which implies volatility in the marketer's costs, will in either event directly affect a forward contract's profit variance.

As seen from figure 1, spot-price volatility may be substantial, with daily spot prices that can, within a few days, spike several hundred folds, from under $50 per megawatt-hour (MWH) to $2,600 per MWH. Even though such price spikes may reflect the operation of a rational market (Michaels and Ellig, 1999), they nonetheless subject the marketer to significant potential loss that can easily result in bankruptcy. For example, a 100 MW forward contract with 16-hour delivery at a fixed price of $50/MWH yields daily revenue of $80,000 (= 100 MW x 16 hours x $50/MWH). When the spot price spikes to $2,600/MWH, as it did at the ComEd market in late June 1998, the daily cost rockets to $4,160,000 (=100 MW x 16 hours x $2,600/MWH). The total loss on that fateful day can be a staggering $4.08 million.

This paper considers the problem of determining the financial risks of a forward contract under which a power marketer agrees to provide electricity at a fixed price per MWH for a given delivery period, say one year, that begins sometime after contract signing. The marketer's problem is that although there is a pre-established delivery price, the price or opportunity cost that it will have to pay for that electricity on any given day is subject to the vagaries of highly volatile and unpredictable spot markets. Therefore the marketer's profit on the forward contract is inherently uncertain, and its problem is to quantify the financial risks associated with a given forward-contract price in this uncertain environment. Knowing such risks will help the marketer to make an informed decision on whether to offer the contract at that forward price.

The solution to the problem posed herein should be of great interest to both practitioners and academics. From the perspective of a practitioner (e.g., a dogmatic power marketer), if a simple cross-hedging strategy is effective and the related financial risk computations are straightforward, they deserve the practitioner's serious consideration for adoption.

From the perspective of an academic, our empirical evidence tests the hypothesis that two geographically close and inter-connected spot markets are integrated and form a single aggregate market. Market integration rationalizes the use of the futures contract for the foreign market to hedge against the large spot-price volatility in the local market. More importantly, almost perfect correlation between the two spot prices implies that a simple hedging strategy is almost 100% effective. Evidence of almost perfect price correlation questions the need for a more complicated and probably more costly strategy involving multiple instruments (e.g., electricity futures with delivery points outside the two spot markets included in the analysis, natural-gas futures, and possibly over-the-counter call options in the local market). To be sure, should the data reject the hypothesis of market integration, this would cast doubt on the common belief of increasing competition in wholesale electricity markets and lead us to conclude that cross hedging is useless in the presence of such market fragmentation.

2. Cross hedging and risk assessment

Consider a power marketer who wishes to sell a forward contract at a fixed price of \$$G$/MWH in local market "1". There is no forward trading in that local market, although active forward trading takes place in a foreign market "2". The forward price at market "2" is \$$F$/MWH.

To hedge against the local market's spot price volatility, the marketer implements a simple cross-hedging strategy (see, for example, Anderson and Danthine, 1981, for a theoretical exposition) by conducting the following transactions:

- Buy spot electricity on day t at \$$P_{1t}$/MWH in the local market to serve the local forward contract. This results in a day-t per MWH profit of $\pi_{1t} = G - P_{1t}$.

- For each MWH sold under the local market's forward contract, buy β MWH at the fixed price \$$F$/MWH in the foreign market and resell the contract's electricity at the foreign market's day-t spot price of \$$P_{2t}$/MWH. This results in a day-t per MWH profit of $\pi_{2t} = \beta\,(P_{2t} - F)$.

These two transactions lead to a combined per MWH profit on day t equal to

$$\pi_t = \pi_{1t} + \pi_{2t} = (G - P_{1t}) + \beta\,(P_{2t} - F). \qquad (1)$$

The marketer's two-pronged problem is to determine both G and β, given the inherent volatility in the two spot prices. What is apparent from equation (1), however, is that once β has been determined, the variance in profit, σ_π^2, will be a function of both the price variances in the respective markets, σ_1^2 and σ_2^2, and the covariance between the two spot-market prices, σ_{12}. Specifically:

$$\sigma_\pi^2 = \sigma_1^2 + \beta^2\sigma_2^2 - 2\beta\sigma_{12}. \qquad (2)$$

Hence, the profit variance will be lower than otherwise, *ceteris paribus*, when the spot prices are positively correlated. As reported for selective markets in Woo *et al*. (1997), this is indeed often the case for adjacent spot electricity markets. Suppose, then, that an increase in P_{2t} is on average accompanied by a rise in P_{1t}. The incremental loss in π_{1t} is ΔP_{1t} and the incremental gain in π_{2t} is $\beta\Delta P_{2t}$. If $\Delta P_{1t} = \beta\Delta P_{2t}$, the combined profit π_t would on average remain unchanged.

The success of the marketer's cross-hedging strategy assumes a spot-price relationship between the local and foreign markets. Let α denote a parameter, and let ε_t denote a day-t random-error term with the usual IID independence and normality properties. In particular, with E the expectations operator, $E[\varepsilon_t] = 0$ and $E[\varepsilon_t^2] = \sigma_\varepsilon^2 \geq 0$.

Suppose the spot-price relationship remains unchanged over the local forward contract's delivery period and that it is described by the linear regression equation

$$P_{1t} = \alpha + \beta P_{2t} + \varepsilon_t. \tag{3}$$

Here, P_{1t} is the local market's average of hourly spot prices for the M delivery hours on day t, and P_{2t} is the foreign market's average of hourly spot price for the same M delivery hours on that day. It is immediately verified that $\Delta P_{1t} = \beta \Delta P_{2t}$. Hence, on average the spot-price fluctuations in the two markets will cancel each other out insofar as their impact on the marketer's total profits is concerned, provided that its purchases in the foreign market are set equal to β, the regression's slope parameter. Then, substituting equation (3) into equation (1) yields:

$$\pi_t = G - \alpha - \beta F - \varepsilon_t. \tag{4}$$

As reflected in equation (4), because of the linear relationship between the daily spot prices in the two markets, over the local forward contract's delivery period, daily profit does not depend on those spot prices. Moreover, as the first three terms on the right-hand side of equation (4) are fixed, π_t varies only with the locational basis risk ε_t. Arising as it does from random error, this basis risk cannot be removed by cross hedging. Thus β is the optimal hedge ratio that minimizes the variance of π_t (Siegel and Siegel, 1990, Chapter 3). With the parameter vector $\boldsymbol{V} = (\alpha, \beta)$ known, the variance of π_t is now given by $\sigma_\pi^2 = \sigma_\varepsilon^2$, as opposed to the formulation of equation (2).

In practice, however, the vector $\boldsymbol{V}$ is not known. Nonetheless, the marketer does have two clear alternatives for dealing with this aspect of the problem. In the first of these, the marketer applies ordinary least squares (OLS) to estimate equation (3). With e_t

denoting the day-t residual from a sample of n historical observations, and $\boldsymbol{V_e} = (a, b)$ the OLS estimate of $\boldsymbol{V}$, the estimated equation is:

$$P_{1t} = a + bP_{2t} + e_t. \tag{3'}$$

Then, the marketer behaves *as if* equation (3') is the true regression equation. The variance of the residuals, $s_e^2 = \Sigma e_t^2/(n - 1)$ with n being the size of the sample used to estimate equation (3'), is used as the unbiased estimator of σ_ε^2 in the above machinations and through the subsequent analysis (Woo *et al*., 1999).

Alternatively, in Bayesian fashion the uncertain $\boldsymbol{V}$ is considered to be a random vector. The marketer is then asked to assess a multi-normal density over $\boldsymbol{V}$. As Berger (1985, p. 168) remarks: "The most natural focus is to use the data to estimate the prior distribution or the posterior distribution." That distribution can then be revised in typical Bayesian fashion as additional sample information is received in the form of further observations on the prices in the two markets (Raiffa and Schlaifer, 1961, Chapter 12). Under this second, empirical Bayes, approach the marketer's assessed prior distribution over $\boldsymbol{V}$ has a mean of $\boldsymbol{V_e} = \mathrm{E}[\boldsymbol{V}]$, and the prior variances of the two parameters, σ_α^2 and σ_β^2, are assigned by using the respective standard errors from the estimated regression, s_a^2 and s_b^2. The OLS covariance, s_{ab}, is used as the prior covariance, $\sigma_{\alpha\beta}$. In the most readily applied version of the subsequent procedure, the variance of the residuals, s_e^2, is taken to be the known population variance of the random-error term (Raiffa and Schlaifer, 1961, pp. 310-312).

From equation (4), the expected daily per MWH profit is computed to be:

$$\mathrm{E}[\pi_t] = G - \mathrm{E}[\alpha] - \mathrm{E}[\beta]F - \mathrm{E}[\varepsilon_t] = G - a - bF. \tag{5a}$$

The daily per MWH profit variance is now computed as:

$$s_\pi^2 = s_a^2 + F^2 s_b^2 + 2F s_{ab} + s_e^2. \tag{5b}$$

There is a higher profit variance in this mode of analysis than the $s_\pi^2 = s_e^2$ that would be used in the first mode. The increased variance stems from the fact that in the first mode the marketer has, in effect, assigned a dogmatic prior over ***V***. The marketer's dogmatism is reflected in its behaving as if the estimated regression coefficients are indeed the true regression coefficients. That behavior results in the marketer's setting the standard errors of those coefficients, and the covariance between them, equal to zero.

As the linear combination of normal densities, the daily per MWH profit is also normally distributed:

$$\pi_t \sim \mathrm{N}(G - a - bF,\ s_a^2 + F^2 s_b^2 + 2F s_{ab} + s_e^2). \tag{5c}$$

We may therefore directly compute the probability of making a per MWH daily profit above a predetermined threshold π_T (say, zero):

$$\mathrm{prob}(\pi_t > \pi_T) = \mathrm{prob}\{(\pi_t - \mathrm{E}[\pi_t])/s_\pi > (\pi_T - \mathrm{E}[\pi_t])/s_\pi\}. \tag{6}$$

We can use equation (6) in combination with equation (5a) to solve for a particular value for G that would yield a target probability of positive profit. Suppose G is initially set at $(a + bF)$. The latter results in an expected profit of zero, with a variance of s_π^2 computed from equation (5b). At $G = a + bF$, $\mathrm{prob}(\pi_t > 0) = 0.5$. To improve $\mathrm{prob}(\pi_t > 0)$ to a target of $p_T > 0.5$, we increase G by $z s_\pi$, where z is the standard normal variate corresponding to p_T. In particular, $z = 1.65$ if $p_T = 0.95$. Thus the pricing rule for positive profit with this degree of certainty is:

$$G_{0.95} = a + bF + 1.65 s_\pi. \tag{7}$$

Thus far we have been dealing with the expected value and volatility of the daily per MWH profit in connection to the two forward prices (G, F) and the estimated inter-market spot-price relationship. But the local forward contract may have more than one delivery day. Suppose the contract has L delivery days. The forward contract is profitable if $\mu = \Sigma\pi_t/L$, the average of the daily per MWH profits over the L delivery days, is positive. As π_t is normally distributed, so is μ, with $E[\mu] = G - a - bF$ and $s_\mu^2 = s_\pi^2/L$; or,

$$\mu \sim N(G - a - bF, (s_a^2 + F^2 s_b^2 + 2Fs_{ab} + s_e^2)/L).$$

Proceeding in a manner similar to the case of the daily per MWH profit, the marketer can derive the probability that the forward contract with L delivery days will be *ex post* profitable. Letting μ_T denote the threshold for the average of daily per MWH profits:

$$\text{prob}(\mu > \mu_T) = \text{prob}\{(\mu - E[\mu])/s_\mu > (\mu_T - E[\mu])/s_\mu\}.$$

We recognize that besides the number of delivery days, the marketer's total risk exposure critically depends on the megawatt (MW) size of the local forward contract. Suppose the contract's total electricity delivery at the 100% rate is $Q = KLM$, where K = MW size, L = number of delivery days in the contract period, and M = number of delivery hours per delivery day. The contract's expected total profit is:

$$\Pi = QE[\mu] = Q(G - a - bF).$$

The total profit variance is:

$$s_\Pi^2 = Q^2 s_\mu^2.$$

Following Jorion (1997), we use $\text{prob}(\Pi < \text{VAR}) = 0.05$ to derive the contract's value at risk:

$$\text{VAR} = Q(G - a - bF - 1.65s_\mu) \quad (8)$$

Equation (8) states the marketer's maximum loss under normal circumstances. In other words, there is less than a 5% chance that the marketer's *ex post* loss after the realization of market spot prices will exceed the VAR in equation (8).

The profitable price $G_{0.95}$ in equation (7) and the VAR in equation (8) are closely related. The relationship is that if $G = G_{0.95}$, then VAR = 0. Should G be above (below) $G_{0.95}$, VAR is positive (negative). This shows how the marketer can systematically revise G to improve the probability of profit and to reduce the VAR.[1]

3. An illustration

We use two different pairs of geographically separated real-world markets to illustrate our approach. The first pair, in the Mid-West, comprises Commonwealth Edison (ComEd) in the role of market “1”, the local market with spot trading only, and Cinergy in the role of market “2”, the foreign market with both spot and futures trading. The second pair, in the Pacific Northwest, comprises Mid-Columbia (Mid-C) in the role of the local market and the California-Oregon border (COB) in the role of the foreign market. For each pair we retain the assumption that the power marketer would sell the forward contact in the local market and cross hedge via the purchase of a strip contract (a series of 12 monthly forward contracts) with delivery in the foreign market. The local forward contract is for 16-hour on-peak (06:00 - 22:00, Monday to Friday, except public holidays) delivery throughout a local contract period that is assumed to be one year. Computations for a local contract with a shorter time period are entirely analogous.

The first pair, ComEd/Cinergy, represents emerging markets that one would expect to be associated with larger basis risk than would be the case with the more mature Mid-C/COB tandem. The former pair has tended to have the more volatile and higher spot prices than the latter pair. In particular, the ComEd/Cinergy pair has proved to be very vulnerable to such unanticipated events as the hot weather and plant outages in June and July of 1998. We would therefore expect cross hedging to be less effective for that pair than for Mid-C/COB, and consequently we would expect more risks for the power marketer in ComEd versus its Mid-C counterpart.

3.1. Estimation

The presumptive first stage in our procedure is to obtain the estimated spot-price regression, equation (3') and the associated standard errors, using the daily spot-price data for each market pair. The resulting estimates, however, can be misleading and subject to spurious interpretation if the price series (P_{1t}, P_{2t}) are random walks (e.g., $P_{it} = P_{i(t\text{-}1)}$ + error, i = 1, 2) that may drift apart over time. Such drifting can cause the basis risk as reflected in the residuals to grow over time, rendering the cross hedge useless. To guard against this possibility, prior to relying on the estimated parameters from equation (3') we first test the null hypotheses that (P_{1t}, P_{2t}) are random walks and that (P_{1t}, P_{2t}) drift apart over time.

The test statistic for the random-walk hypothesis is the Augmented Dickey-Fuller (ADF) statistic whose critical value for testing at the 1% level is -3.4355. The ADF statistic is the t-statistic for the OLS estimate of δ in the regression $\Delta v_t = \delta v_{t\text{-}1} + \phi \Delta v_{t\text{-}1}$ + white noise. The variable v_t is the residual in the estimated regression $P_{it} = \gamma_0 + \gamma_1 P_{i(t\text{-}1)}$ + η_t, where η_t is a random-error term with the usual normality properties. This test, then, is a unit-root test.

Table 1 reports some summary statistics of daily on-peak spot prices, as well as the ADF statistics, for all four markets for our sample period of June 1, 1998 to May 31, 1999. The sample period is so chosen as to highlight how cross hedging may be used in a highly uncertain market-price environment.

The summary statistics indicate that the spot-price distributions are skewed to the right, with the median price below the mean price. The non-normal price distribution, however, should not prevent our empirical implementation. First, least-squares regression yields unbiased coefficient estimates. Second, such measurements of risk as profit volatility, probability of positive profit and value at risk are based on the multi-normal prior density. And, finally, the average of the daily per MWH profits is normally distributed under the Central Limit Theorem.

The standard deviations in table 1 reflect the fact that Mid-C and COB spot prices are generally lower and less volatile than are the ComEd and Cinergy spot prices, which fuels our expectation of lower $G_{0.95}$ and VAR for the Mid-C market versus the ComEd market. The ADF statistics indicate that none of the four price series is a random walk, implying that we need not discredit any estimated spot-price relationship on random-walk grounds.

To understand the behavior of the so-called regional basis (i.e., the difference between two locational spot prices), we plot the daily spot prices for each market pair in figures 2.A and 2.B. These figures indicate that the regional basis widens during high-price days. Our review of the events during those days suggests that the size of the regional basis increases with the extent of transmission congestion that prevents the unfettered flow of power between the two inter-connected markets.

We apply the cointegration test to test the hypothesis that the (P_{1t}, P_{2t}) pair drift apart over time. The test statistic is an ADF statistic, with -3.9001 being the critical test value at the 1% level.[2] The estimation results for both market pairs, as well as the ADF statistics for the two regressions, are given in table 2. The ADF statistics indicate that we can safely reject the hypothesis that the two spot-price series in either market pair drift apart. The statistics lead us to infer that both market pairs comprise substantially, if imperfectly, related markets

Moreover, the markets within each pair would appear to be integrated such that they are slightly differentiated markets within a larger overall market. Evidence of market integration would support the use of the futures contract for the foreign market to hedge against the price volatility in the local market. The first evidence of market integration is that the value for *b* is 1.082 for the Mid-C/COB estimated regression and is 1.093 for the ComEd/Cinergy regression, implying that a $1 price change in either foreign market is accompanied by an approximately equal change in its companion local market. Consistent with the law of one price, absent persistent congestion that hinders inter-market trading, the price in one market should, on average, equal the price in an adjacent market plus the cost of transmission. The second piece of evidence is that the values for *a* of -4.097 for the Mid-C/COB estimated regression and of -5.010 for the ComEd/Cinergy regression, do in fact approximate the average costs of transmission between those market pairs.

Despite the evidence of market integration, the simple cross hedging described in section 2 might be ineffective if the ties between the two markets are relatively loose. In the present instance, however, the adjusted-R^2 values for both regressions exceed 0.95. As discussed and described in detail in Woo *et al*. (1997), the latter confirm the tight ties that exist between these market pairs. The marketer can therefore be confident of nearly 100% hedge effectiveness. Thus these two market pairs do not call for a more complicated and probably more costly strategy involving multiple instruments (e.g., electricity futures with delivery points outside the two spot markets included in the analysis, natural-gas futures, and possibly over-the-counter call options in the local market). While this finding is specific to the Mid-C/COB and ComEd/Cinergy market pairs, it does indicate the usefulness of the simple strategy.

In light of the evidence of market integration and the goodness of fit of both estimated regressions, a power marketer may now feel comfortable in using the regression results to assign its non-dogmatic prior densities and to thence implement cross hedging and assess the risks inherent in the local contract.

3.2. Empirical results

By altering the price of the local contract, we develop alternative estimates for the contract's expected total profit, the probability of a positive profit, and VAR. For the sake of illustration, we make the following assumptions:

- The local forward contract's size is 100 MW, enough to serve approximately 30,000 residential homes. The one-year contract has 256 delivery days and 16 delivery hours per day. Thus the contract's total electricity delivery is 409,600 MWH.
- The 12-month forward price with delivery beginning 08/99 is \$35/MWH at the COB market and \$39/MWH at the Cinergy market (Source: Settlement prices on 07/06/99 based on the information on www.powermarketers.com).

Table 3.A shows that when the Mid-C contract is priced at or below \$33/MWH, the contract is not likely (less than a 1% chance) to be profitable. At \$30/MWH, the expected total loss can be as large as \$1.5 million and the VAR is \$1.6 million. At \$33.75/MWH, the Mid-C contract's expected profit is zero and the VAR is -\$0.115

million. But if the Mid-C contract price can be raised to \$34/MWH, the probability of positive profit rises to $p^+ > 0.90$ and the VAR dwindles to \$0.016 million. At $G_{0.95}$ = \$34.04, the probability of positive profit is $p^+ = 0.95$ and the VAR becomes zero. Adding \$1/MWH to $G_{0.95}$ ensures the contract's profitability with almost certainty ($p^+ > 0.99$).

Table 3.B shows that when the ComEd contract is priced below \$37/MWH, the contract's probability of positive profit is $p^+ < 0.40$. At \$36/MWH, the expected total loss is \$0.674 million but the VAR is large at \$2.33 million. At \$37.64/MWH, the ComEd contract is expected to break even but it still has a VAR equal to \$1.65 million, over 13 times the -\$0.115 million VAR for the Mid-C contract at the break-even price of \$34.76/MWH. If the ComEd contract price can be raised to \$41.69/MWH, the probability of positive profit rises to over 0.95 and the VAR diminishes to \$0.00. To make the ComEd contract profitable with almost certainty ($p^+ > 0.99$), the power marketer would need to raise the price by another \$2.4/MWH to \$44/MWH. Thus the ComEd contract is more risky than the Mid-C contract because the ComEd/Cinergy market pair has more volatile and higher spot prices than does the Mid-C/COB pair.

Having determined the alternative forward price levels at the Mid-C and ComEd markets, it might have been interesting to compare them with actual forward prices observed in these markets. Such a comparison would shed light on the price-making behavior and risk aversion of power marketers. For instance, if the actual forward prices tend to be at the low end of those in tables 3.A. and 3.B, we can infer that power marketers price aggressively and are not risk averse. Unfortunately, forward prices for Mid-C and ComEd are unavailable; otherwise, cross hedging would have become unnecessary.

4. Conclusion

Volatile spot prices and incomplete forward markets motivate our consideration of an electric-power marketer who sells a fixed-price contract to a wholesale buyer. The marketer implements cross hedging to reduce the risk of the fixed-price contract with delivery to a local market that does not have forward trading. Using a spot-price relationship between two wholesale electricity markets, we show how the marketer may hedge against the spot-price volatility, determine a forward price, assess the probability of making an *ex post* profit, compute the contract's expected profit, and calculate the contract's value at risk. Such information is useful to the marketer's decision making.

We demonstrate our approach using spot-price data for two pairs of wholesale markets: Mid-C/COB and ComEd/Cinergy. The regression results for both market pairs support our contention that the spot-price relationship is not spurious and can be used for the purpose of cross hedging, pricing, and risk assessment. The empirical results confirm our expectation that a forward contract with ComEd delivery is more risky than one with Mid-C delivery because the ComEd/Cinergy market pair's spot-price volatility is substantially larger than that of the Mid-C/COB market pair. Finally, the simple cross-hedging strategy is effective for these market pairs and calls into question the need for a more complicated and probably more costly strategy.

Notes

1. Equation (7) shows that any G is an increasing function of s_π. Hence, the non-dogmatic marketer will, *ceteris paribus*, choose a higher G than will that marketer's dogmatic counterpart. The higher G is reflective of the non-dogmatic marketer's uncertainty as to the true values of the regression parameters α and β. Indeed, our approach implicitly assumes that the marketer will set the price *and* the amount to purchase in the second market (that is, β) simultaneously, with the profit in the first market *always* being uncertain because one never knows the true α, and the profit earned in the second market uncertain *a priori* because one never knows the true β.

An alternative approach to the problem would assert that once the regression has been estimated the marketer knows with certainty that the profit in the second market will be $b(P_{2t} – F)$. In this case, the total profit will be given by: $G - \alpha + (b - \beta)P_{2t} – bF - \varepsilon_t$. Repeating the earlier machinations, it is immediately determined that the expected profit is again computed as in equation (5a). It can also be verified that the variance differs from that of equation (5b), only insofar as the term $F^2 s_b^2$ is replaced by $P_{2e}^2 s_b^2$, where P_{2e} is the expected price in the second market. Most assuredly, that expected price will be less than F. Hence, this approach will yield a lower variance than will the approach that we adopt. Thus, our approach is the most inherently conservative approach to the problem, because it is that which gives the highest variance.

2. See Davidson and MacKinnon (1993) for a description of the unit root and cointegration tests, and Woo *et al*. (1997) for their applications in an analysis of electricity spot prices.

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*Figure 1***.** Daily on-peak spot prices at the ComEd market during 06/01/98 – 07/31/98.

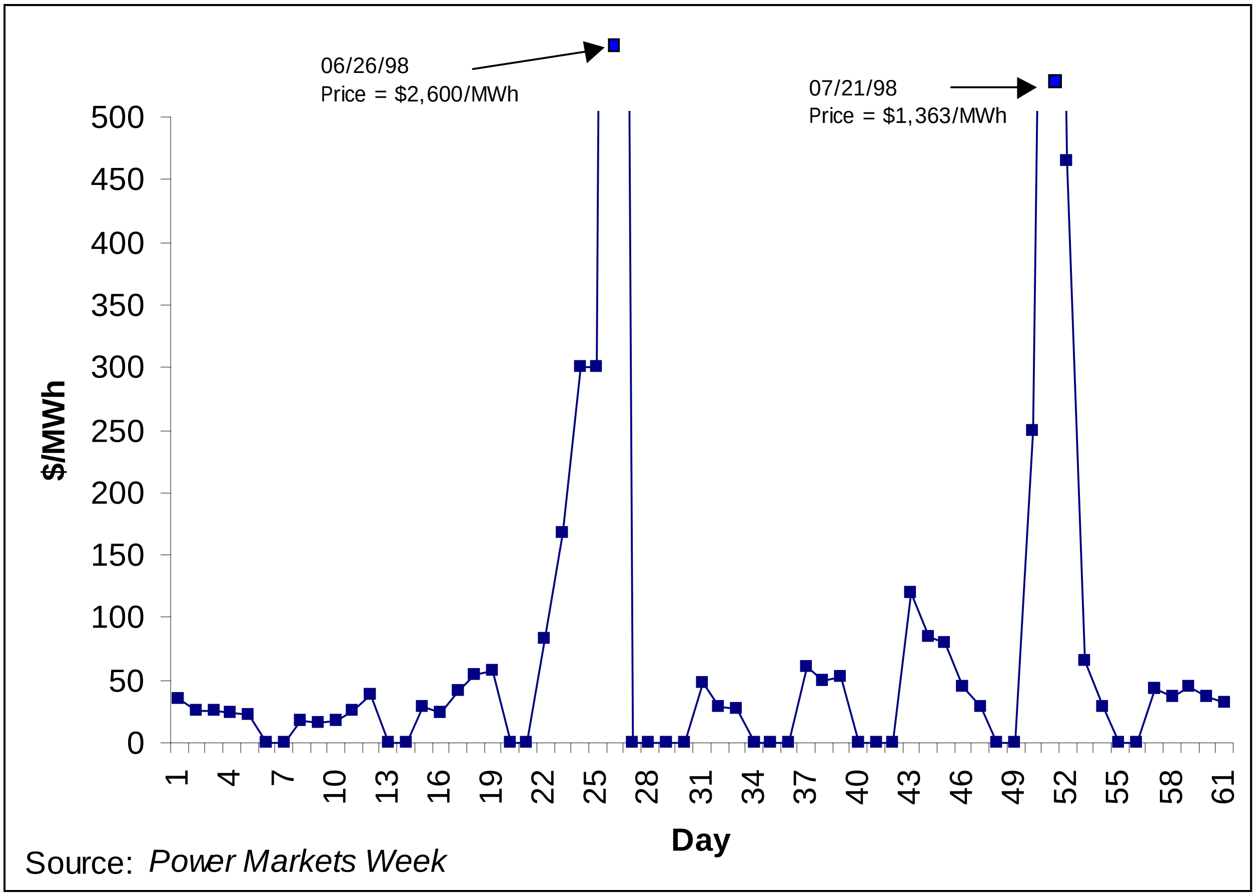
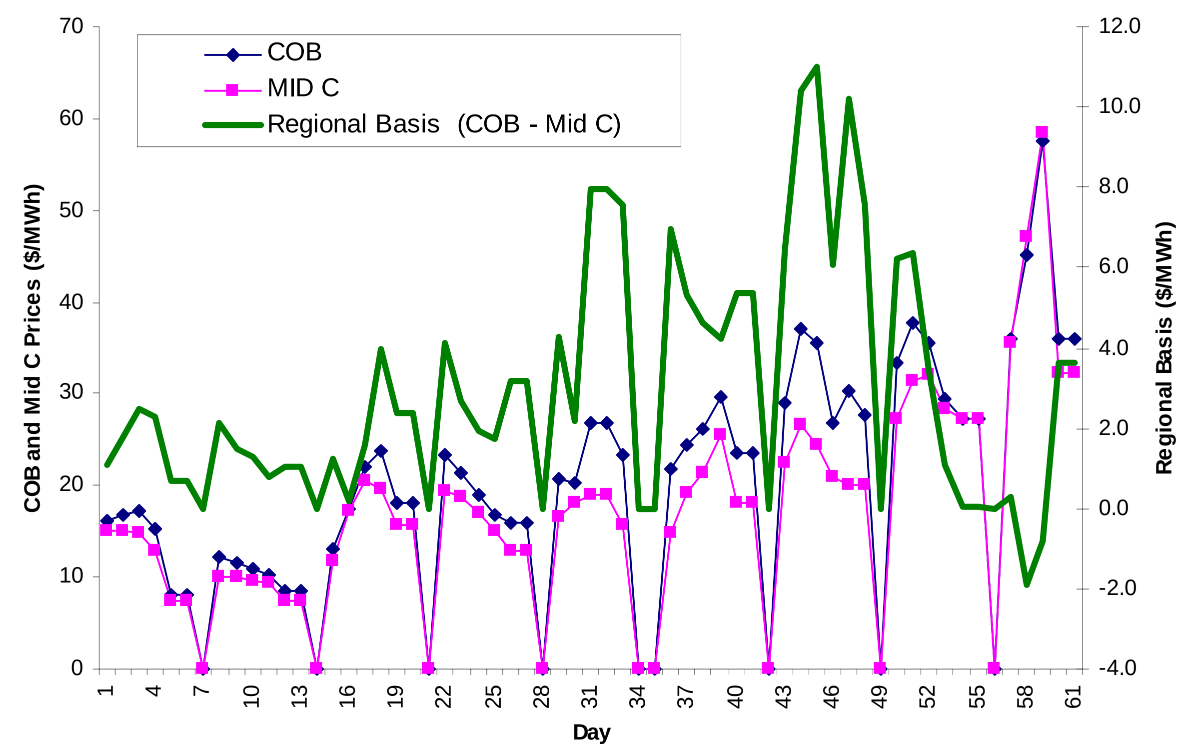


Figure 2A. Regional basis and spot prices for the Mid-C/COB market pair during 06/01/98 – 07/31/98

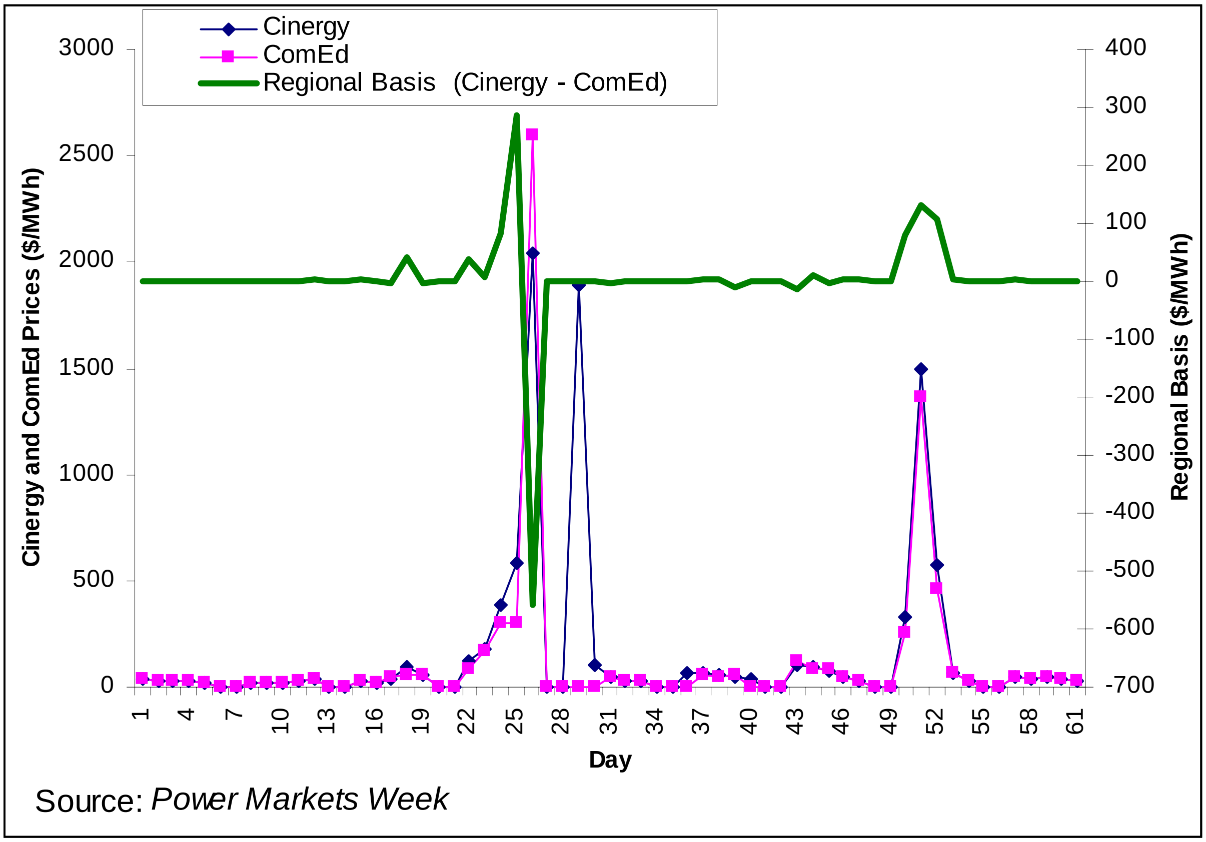


Source: *Power Markets Week*

Note: Spot prices and regional basis for Mid-C/COB market pair during the 30 Days (06/01/98 – 07/31/98) with the highest regional basis, sorted in ascending order by the size of regional basis

Day [A]	Date [B]	COB [C]	Mid-Columbia [D]	Regional Basis [E] = Abs ([C] - [D])	Day [A]	Date [B]	COB [C]	Mid-Columbia [D]	Regional Basis Abs ([C] - [D])
1	07/15/98	36	25	11	16	07/08/98	26	21	5
2	07/14/98	37	27	10	17	06/29/98	21	17	4
3	07/17/98	30	20	10	18	07/09/98	30	25	4
4	07/01/98	27	19	8	19	06/22/98	23	19	4
5	07/02/98	27	19	8	20	06/18/98	24	20	4
6	07/03/98	23	16	8	21	07/30/98	36	32	4
7	07/18/98	28	20	8	22	07/31/98	36	32	4
8	07/06/98	22	15	7	23	07/22/98	36	32	3
9	07/13/98	29	22	6	24	06/26/98	16	13	3
10	07/21/98	38	31	6	25	06/27/98	16	13	3
11	07/20/98	33	27	6	26	06/23/98	21	19	3
12	07/16/98	27	21	6	27	06/03/98	17	15	2
13	07/10/98	24	18	5	28	06/19/98	18	16	2
14	07/11/98	24	18	5	29	06/20/98	18	16	2
15	07/07/98	25	19	5	30	06/04/98	15	13	2

Figure 2B. Regional basis and spot prices for the ComEd/Cinergy market pair during 06/01/98 – 07/31/98



Note: Spot prices and regional Basis for ComEd/Cinergy market pair during the 30 Days (06/01/98 – 07/31/98) with the highest regional basis, sorted in ascending order by the size of regional Basis

Day [A]	Date [B]	Cinergy [C]	ComEd [D]	Regional Basis Abs ([C] - [D])	Day [A]	Date [B]	Cinergy [C]	ComEd [D]	Regional Basis Abs ([C] - [D])
1	06/26/98	2040	2600	560	16	07/16/98	49	45	4
2	06/25/98	588	300	288	17	06/19/98	54	58	3
3	07/21/98	1493	1363	130	18	07/07/98	64	61	3
4	07/22/98	572	465	107	19	07/01/98	45	48	3
5	06/24/98	383	300	83	20	06/17/98	39	42	3
6	07/20/98	330	250	80	21	07/27/98	46	44	3
7	06/18/98	96	55	41	22	07/17/98	32	29	2
8	06/22/98	121	83	38	23	06/12/98	40	38	2
9	07/13/98	106	120	14	24	06/15/98	31	29	2
10	07/14/98	97	85	12	25	07/29/98	47	45	2
11	07/09/98	44	52	9	26	07/30/98	38	36	2
12	06/23/98	175	168	7	27	07/28/98	39	37	1
13	07/08/98	55	50	5	28	06/02/98	27	26	1
14	07/15/98	76	80	4	29	06/05/98	21	22	1
15	07/23/98	69	65	4	30	06/11/98	26	25	1

Table 1. Summary statistics and ADF statistics of daily on-peak spot prices (US$/MWH) by market for the sample period of 06/01/98 – 05/31/99

Statistics	COB	Mid-C	Cinergy	ComEd
Sample size	256	256	256	250
Mean	29.31	27.61	55.74	47.94
Minimum	8.15	7.42	14.15	15.50
First quartile	21.51	18.75	18.51	19.50
Median	26.89	25.24	23.31	23.51
Third quartile	31.56	30.73	29.25	28.54
Maximum	85.91	87.65	2040.48	2600.00
Standard deviation	12.87	14.19	201.79	187.45
ADF statistic for testing H_0: The price series is a random walk	-4.26*	-9.25*	-4.58*	-9.35*

Notes: (a) The ComEd market only has 250 observations because of missing price data. (b) The ADF statistic's critical value is –3.4355 at the 1% level. (c) "*" = "Significant at the 1% level and the null hypothesis is rejected." (c) Source: Power Markets Week.

Table 2. On-peak spot-price regressions by market pair

Independent variables	Dependent variable	
	Mid-C price	ComEd price
Intercept	-4.097 (-9.64)*	-5.01 (-1.94)
COB price	1.082 (81.43)*	
Cinergy price		1.093 (73.87)*
Adjusted R^2	0.9630	0.9563
Mean squared error	7.46	1533.8
ADF statistic for testing H_0: The two price series drift apart without limit	-6.92*	-11.53*

Notes: (a) t-statistics in ( ) and "*" = "Significant at 1% and the null hypothesis that the coefficient equal to zero is rejected". (b) The ADF statistic's critical value is -3.9001 at the 1% level.

Table 3.A. Forward price, probability of positive profit, expected total profit, and value at risk of a 1-year, 100-MW forward contract with 16-hour on-peak delivery at Mid-Columbia.

Mid-C forward price ($/MWH)	Probability of positive profit (%)	Expected total profit ($000)	Value at risk with 5% chance ($000)
30	0.0	-1,539	-1,655
31	0.0	-1,130	-1,246
32	0.0	-720	-836
33	0.0	-310	-426
33.76	50	0	-115
34	92	98.8	-16
34.05	**95**	**121**	**0**
35	Over 99	508	393
36	Over 99	918	802

Note: The price for a 12-month forward contract with COB delivery is assumed to be $35/MWH. At this COB price, the variance of the average of daily per MWH profit is s_μ^2 = $0.032/MWH. The Mid-C price in **bold** is $G_{0.95}$ that achieves a 95% probability of positive profit and a zero VAR.

Table 3.B. Forward price, probability of positive profit, expected total profit, and value at risk of a 1-year, 100-MW forward contract with 16-hour on-peak delivery at ComEd.

ComEd forward price ($/MWH)	Probability of positive profit (%)	Expected total profit ($000)	Value at risk with 5% chance ($000)
36	25	-674	-2,332
37	40	-264	-1,923
37.64	50	0	-1,658
38	56	145	-1,513
39	71	554	-1,103
40	83	964	-694
41	91	1,374	-284
41.69	**95**	**1,658**	**0**
42	96	1,783	125
43	99	2,193	534
44	Over 99	2,603	945

Note: The price for a 12-month forward contract with Cinergy delivery is assumed to be $39/MWH. At this Cinergy price, the variance of the average of daily per MWH profit is s_μ^2 = $6.02/MWH. The ComEd price in **bold** is $G_{0.95}$ that achieves a 95% probability of positive profit and a zero VAR.