

Cross Hedging and Forward-Contract Pricing of Electricity

Energy Economics, forthcoming.

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ABSTRACT

We consider the problem of an electric-power marketer offering a fixed-price forward contract to provide electricity that it purchases from a potentially volatile and unpredictable fledgling spot energy market. One option for the risk-averse marketer who wants to hedge against the spot-price volatility is to engage in cross hedging to reduce the contract's profit variance, and to determine the forward-contract price as a risk-adjusted price -- the sum of a baseline price and a risk premium. We show how the marketer can estimate the spot-price relationship between two wholesale energy markets for the purpose of cross hedging, as well as the optimal hedge and the forward contract's baseline price and risk premium.

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I. INTRODUCTION

Recent regulatory reforms at the federal levels have led to a profound restructuring of the industry (Joskow, 1997; Woo *et al.*, 1997). The passage of the 1978 Public Utilities Regulatory Policy Act (PURPA) sparked the early development of a competitive power generation industry. The 1992 Energy Policy Act provides 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 energy markets at major delivery points of the high-voltage transmission grids in the U.S.

Wholesale energy trading has grown exponentially, dominated by power marketers not affiliated with electric utilities (Seiple, 1996). In addition to spot-market trading, a power marketer offers fixed-price forward contracts to wholesale buyers such as electric utilities that resell the energy to their retail customers. Because a forward contract obligates a power marketer to deliver energy at a specific location, it exposes the marketer to volatile spot energy 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 energy 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.

Parallel to the trend of federal deregulation, many states initiated their own deregulatory efforts. Electricity consumers in California, New York, Pennsylvania and New England can now buy energy from any supplier, including a power marketer. This is notwithstanding that the purchased energy is still delivered over the networks of regulated electric utilities or wires companies in these states. To enter the retail energy market, a power marketer sells forward contracts, which are popular among electricity consumers. A forward contract's popularity with consumers is understandable. The contract gives electricity consumers something with which they are familiar and comfortable: notably, consuming electricity at a fixed price, as was done before the advent of deregulation. The sale of a forward contract by a power marketer in the retail energy market, however, also exposes the marketer to spot price volatility.

This paper considers the problem of pricing a forward contract under which a power marketer agrees to provide electricity at a fixed price per megawatt hour (MWH) for a given period of time (e.g., one year). The marketer's problem is that although there is 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 determine the forward-contract price(s) in this uncertain environment.

A risk-neutral power marketer can resolve the problem by assigning a probability density to describe the stochastic spot-price process, quantifying the various demand and supply components that are needed to determine the optimal contract, and then employing standard optimization procedures to determine the forward prices that

maximize expected profit. Our focus, however, is on a risk-averse power marketer that may be more representative of the real-world marketer than is the expected-profit-maximizing risk-neutral marketer.

Proceeding like its risk-neutral counterpart, the risk-averse power marketer could first assess a von Neumann-Morgenstern risk-preference function and then determine the forward-contract prices that would maximize expected utility. A more practical and readily implemented alternative is for the marketer to hedge by purchasing a futures contract that locks in the price it will pay for the electricity that it resells. If the marketer offers the forward contract in a market that is served through a mature spot energy market that also has active trading of futures and options, a perfect hedge can be achieved and the profit uncertainty can be completely eliminated.

Suppose, however, that the power marketer is one of many players in one of the growing number of spot energy markets, many of which lack sophisticated financial instruments. Fledgling markets that are either not yet active or that have only recently become active will almost certainly fall into this category. In this case, the marketer must explore other markets for any *cross*-hedging opportunities that can *reduce*, but not eliminate, the profit variance on its forward contracts, with “the best cross hedge ... calculated in exactly the same way as a standard hedge” (Anderson & Danthine, 1981 p. 1183).¹ The forward-contract prices are then determined as risk-adjusted prices, each of which is the sum of a baseline price and a risk premium. The paper thus has two objectives, the first of which is to show how to identify the most viable market(s) for the purpose of cross hedging. The second objective is to show how the baseline prices and the risk premium can be determined, given the previously determined market(s).

II. WHOLESALE MARKET PRICE AND FORWARD CONTRACTS

Electric energy trading occurs on regionally disparate wholesale markets. Thanks to modern technology and open access to transmission networks, buyers and sellers have the opportunity to export and import power between regions. And when there is interregional trading there will be some linkage between the regional prices. Where the regional markets comprise a single market, the “law of one price” prevails. The law tells us that the regional prices will differ only by transportation *qua* transmission costs, and that any price changes in one of the markets will be perfectly correlated with the price changes in the other(s). In point of fact, however, market imperfections assure that the correlation between the prices in one market and the prices in another with which it shares some ties will be imperfect, too. Still, positively correlated regional power-market prices afford all traders, including power marketers and utilities, hedging options that can ameliorate the adverse effects of short-term price volatility.²

In particular, we consider a power marketer that offers 12-month fixed-price contracts in year $T-1$ to deliver electricity during year T to energy buyers in location M_1 . The marketer intends to fulfill its contractual obligations by purchasing spot energy in M_1 's neophyte spot market, one for which futures and options do not yet exist.

Each day during T , the power marketer suffers (enjoys) an out-of-pocket loss (gain) when the fixed contract price is less (greater) than the spot-market price. The marketer, however, can hedge against these daily fluctuations in its fortunes by identifying a spot market in another location, M_2 , whose prices are positively correlated with those of M_1 . When the correlation is perfect, offers to *purchase* power in M_2 at a fixed price during the contract year and to *sell* it at M_2 's spot prices would allow the

marketer to enjoy (suffer) a profit (loss) in M_2 whenever it suffers (enjoys) a loss (profit) in M_1 . By controlling the quantities of its purchases and sales in these two related markets, the marketer could effect a perfect profit offset. With a perfect price correlation, however, in essence we have a single market, a wheel-spinning power marketer, and the vacuous problem of a simple hedge.

When the price correlation is imperfect, the power marketer can still effect a profit offset, albeit one that is imperfect, by buying a strip contract. The latter is a series of twelve monthly futures contracts that lock in the average purchase cost of one MWH of energy delivered at the rate of one MW per hour. The contract fixes the price for daily year- T delivery in M_2 . The marketer then turns around and offers to sell that electricity on that day's M_2 spot market, knowing full well that the spot prices in M_2 are positively correlated with those of M_1 . Then over the long term any short-term gains or losses in one market will *tend* to be at least partially offset by losses or gains in the other. The long-term effect is to reduce, though not completely eliminate the short-term profit variance.

III. CROSS HEDGING

If there is active trading of futures and options in M_1 , the risk-averse power marketer can directly hedge against spot-price fluctuations in that market by buying a 12-month strip for year- T delivery in M_1 . Suppose, however, that the spot-price energy market in M_1 is an emerging market with relatively thin trading. As such, futures and options are unlikely to be available at the M_1 market's inception and/or during year $T-1$ when the marketer is marketing its futures contracts. This gives rise to the marketer's need for an alternative hedging strategy. The alternative that we propose is a two-pronged strategy.

The first prong involves cross hedging through the power marketer's purchase of a 12-month strip contract in a mature market, M_2 , for delivery of electricity in year T . The second prong involves pricing the forward contract to include a premium for the risk not eliminated by the first prong.

The cross-hedging process entails the use of futures contracts in at least two distinct energy markets with positively correlated prices. In one market, the power marketer agrees to purchase electricity at a fixed price with the intent of reselling it in the spot market; in the second market, the marketer agrees to sell electricity at a fixed price with the intent of purchasing it in the spot market. Before applying the cross-hedging principle to electricity spot markets, however, it is first necessary to make some assumptions as to how the specific markets operate. The simplifying ones that we make here are readily modified to deal with markets for which they are inapplicable, and the modifications are transparent.

We assume that the 12-month strip for M_2 delivery applies to on-peak energy that is delivered during the 16 on-peak hours between 6:00AM and 10:00PM on Monday through Friday. By contrast, in the forward contract for M_1 the power marketer agrees to deliver energy 24 hours a day, seven days a week. The marketer can resolve the delivery mismatch through the following procedure.

Suppose the forward contract only applies to the on-peak hours. Let F_P denote the MWH price for such a contract. Let k denote the average of the on-peak hourly spot prices in M_1 divided by the average of the off-peak hourly spot prices in M_1 . Each average price is the sum of the spot-market prices divided by the total number of hours in

the pricing period. Let $F_O = F_P/k$. Hence, F_O serves as a proxy for the off-peak price if the forward contract had distinguished between on-peak and off-peak delivery prices.

Now let w denote the share of on-peak hours during a 12-month period. With the NYMEX as an important case in point, there are 368 on-peak hours per month in a NYMEX futures contract for two MWs of power, and hence 736 MWH of energy. Thus the annual number of on-peak hours is $(12/2) \times 736 = 4,416$ out of a total of $365 \times 24 = 8,760$ hours, and $w = 4,416/8,760 = 0.5041$. The final contract price of F is the weighted average of the hypothetical on-peak and off-peak prices; or, $F = wF_P + (1 - w)F_O$.³

Having shown how to use an on-peak contract price to derive the prices for all hours during the year, we confine our discussion to on-peak energy only. To implement a cross hedge, the power marketer buys a 12-month strip contract with delivery in M_2 . The price of the strip is S per MWH for Q MW of block power to be delivered during the on-peak hours in year T . After taking delivery on day t , the marketer sells that energy in M_2 during the 16 on-peak hours at an average price of P_{2t} . The day- t profit from the strip is $\pi_{2t} = 16Q(P_{2t} - S)$.

During day t , the power marketer also earns a profit of $\pi_{1t} = 16(F - P_{1t})$ on a one MW forward contract in M_1 , where P_{1t} is the average spot price of energy in that market. The marketer's total profit on day t is the sum of the profits in the two markets; or,

$$\pi_t = \pi_{1t} + \pi_{2t} = 16[(F - P_{1t}) + Q(P_{2t} - S)]. \quad (1)$$

Dividing both sides by 16 yields the day- t profit per MWH, Π_t . Rearranging terms,

$$\Pi_t = (F - SQ) + (QP_{2t} - P_{1t}). \quad (1a)$$

The first term on the right-hand side of equation (1a) is fixed by the terms of the forward contract in M_1 and the strip in M_2 . The second term, however, is sensitive to the

daily spot-price movements in either market. When those spot-price movements have a positive linear correlation we can write

$$P_{1t} = \alpha_0 + \alpha_1 P_{2t} + \varepsilon_t. \quad (2)$$

Here, α_0 and $\alpha_1 > 0$ are regression parameters and ε_t is a random-error term with the usual normality properties. If the M_1 spot market was active for a sufficiently long period of time prior to the power marketer's initiation of the joint forward-contract, cross-hedging process for year T , the available data on P_{1t} could be used to obtain estimates of the regression parameters α_0 and α_1 . The estimates are denoted a_1 and a_2 , respectively. If, however, M_1 spot-market trading activities are only scheduled to begin in year T , then the marketer requires a data set that would serve to *proxy* the unavailable P_{1t} data in the parameter-estimation process. One appropriate proxy might be the price data from a spot energy market in another location M_3 , which is linked to M_1 via adequate transmission capacity. A second appropriate proxy might be the price data from a spot energy market in location M_4 , whose relationship with M_2 in terms of geographical distance, trading opportunities, and retail energy prices, appears to approximate that of M_1 and M_2 .

To determine Q , the quantity delivered in the M_2 strip, suppose that between day $t-1$ and day t , the price in M_2 increases by \$1. Then, the *expected price change* in M_1 will be a_1 and the *expected change* in the daily profit per MWH will be given by:

$$\begin{aligned} \Delta_t = E[II_t] - E[II_{t-1}] &= (F - SQ) + Q[P_{2(t-1)} + 1] - a_0 - a_1[P_{2(t-1)} + 1] \\ &\quad - (F - SQ) - QP_{2(t-1)} + a_0 + a_1P_{2(t-1)} = Q - a_1. \end{aligned}$$

To make the expected change equal zero and in that sense to have the spot-price changes in one market perfectly offset those in the other, the power marketer should set $Q = a_1$;

or, a_1 MW of block power should be purchased in M_2 . The marketer's subsequent problem is to determine the forward-contract price that will cover the cost of the hedge.

IV. FORWARD-CONTRACT PRICING

A. Baseline Price

The power marketer's reliance on this cross hedge rests on the assumption that the estimated spot price regression equation is valid and remains so for year T . That may be a heroic assumption, particularly if proxy data are used in the estimation process. From the year $(T-1)$ decision-making standpoint of the power marketer, however, the regression's parameter estimates provide the best available information on which to base both cross hedging and pricing decisions. These estimates will therefore be used to determine the forward contract's baseline price and the risk premium.

The forward-contract price, F , is given as the sum of the baseline price, F_B , and a risk premium, ρ . Absent additional information, in order to pass along the acquisition cost of the 12-month strip to the buyer of the forward contract, the power marketer can use the estimated regression to set the baseline price at

$$F_B = a_0 + a_1S = a_0 + QS. \quad (3)$$

That is, the power marketer sets the baseline price on the basis of the *expected* price in the M_1 spot market. Substituting this baseline price into equation (1a) results in the day- t profit per MWH sold:

$$\Pi_t = (F_B + \rho - SQ) + (QP_{2t} - P_{1t}).$$

But, from the estimate of equation (2),

$$P_{1t} - a_1P_{2t} = P_{1t} - QP_{2t} = a_0 + e_t.$$

Here, e_t is the day- t residual. Thus, the day- t profit per MWH sold is:

$$\Pi_t = (a_0 + QS + \rho - SQ) - (a_0 - e_t) = \rho - e_t. \quad (4)$$

The residual is the difference between the *actual* day- t spot-market energy price in M_1 and the *expected* price. As the residual cannot be predicted with certainty it represents the basis risk (Anderson & Danthine, 1981 p. 1183). The day- t profit is therefore seen to be determined as the difference between the risk premium and the basis risk. Prior to day t , however, e_t may be considered to follow a normal process with an expected value of $E[e_t] = 0$ and a variance of s^2 , which is the variance in the residuals for the estimated regression.⁴ Thus, the day- t profit is itself normally distributed with an expected value of ρ , the risk premium, and a variance of s^2 . The volatility of that expected day- t profit is therefore the same as the volatility of the basis risk that cannot be removed by cross hedging.

B. Risk Premium

The higher is the risk premium, the greater is the power marketer's expected profit, because the expected profit *is* the risk premium. But, the higher is the risk premium, the greater is the forward-contract price, which makes the contract less attractive to the customer. Given the market demand for energy sold under forward contracts, and given the power marketer's risk-preference function, the expected-utility-maximizing risk premium could be determined using standard optimization procedures.

As a more practical alternative in the absence of those givens, we propose that the power marketer asks the following question: What is the size of the per MWH risk premium that would allow a positive profit over some pre-determined time period with probability p ? Where the time period is a day, the probability is computed directly from

the normal density, with an expected value of ρ and a standard deviation of s . For $p(\Pi_t > 0) = 0.99$, for example, the risk premium would be $\rho = 2.33s$, since $p(e_t < -2.33s) = 0.99$.

Suppose the marketer wants to set the risk premium so as to give a probability of p that a positive profit will be earned each month of the contract. Consider a month with n days. The per MWH profit during any n -day month will be $\Pi_n = n\rho_n + \sum_t e_t$, where ρ_n is the per MWH premium during that month. The expected monthly profit per MWH is $E[\Pi_n] = n\rho_n$. The monthly-profit variance is $s_n^2 = ns^2$. Therefore, to effect $p(\Pi_n > 0) = 0.99$ requires $n\rho_n = 2.33s_n = 2.33n^{0.5}s$, so that $\rho_n = 2.33sn^{-0.5}$. Similarly, to give a probability of $p(\Pi_a > 0) = 0.99$, where Π_a is the annual profit over the life of a 260-day contract (five days a week for 52 weeks), requires a premium of $\rho_a = 2.33s(260)^{-0.5}$.

In effect, the longer is the power marketer's time horizon in its willingness to risk incurring a loss on the contract with probability $q = 1 - p$, the lower is the per MWH risk premium that it requires. Assuredly, this marketer has to compete with other marketers, some of whom may be less risk averse than it is. In this event, if it wants to sell its forward contract the marketer may have no choice other than to accept a lower risk premium and a lower probability of a positive profit for *any* time period. The procedure we have developed here enables the power marketer to immediately determine the probability that it will incur a loss, in any time period, as a result of meeting a competitor's lower price. The procedure thus enhances the marketer's ability to fully explore the consequences of any pricing policy.

V. 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 M_1 , a market with spot trading only, and Cinergy in the role of M_2 , a market with both spot and futures trading. The second pair, in the Pacific Northwest, comprises Mid-Columbia (Mid-C) in the role of M_1 and the California-Oregon border (COB) in the role of M_2 . For each pair we retain the assumption that the power marketer would sell the forward contract in M_1 and cross hedge via the purchase of a strip contract with delivery in M_2 . Because there are no off-peak futures prices in our M_2 markets, the cross hedge applies to the on-peak hours of 6:00AM to 10:00PM, Monday to Friday. The power marketer's inability to cross hedge in the off-peak hours is not a problem, because (a) the off-peak prices tend to be stable and low; and (b) the marketer can readily establish the forward contract price based on the on-to-off-peak spot price ratio in M_1 (see Section III).

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 a higher risk premium, *ceteris paribus*, for the power marketer in ComEd versus its Mid-C counterpart.

A. Estimation

The presumptive first stage in our procedure is to estimate the spot-price regression of equation (1) 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., $P_{it} = P_{i(t-1)} + \text{error}$, $i = 1, 2$) 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 for equation (1) 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 ordinary-least-squares (OLS) estimate of δ in the regression $\Delta u_t = \delta u_{t-1} + \phi \Delta u_{t-1} + \text{white noise}$. The variable u_t is the residual in the estimated regression $P_{it} = \beta_0 + \beta_1 P_{i(t-1)} + \mu_t$, where μ_t is a random-error term with the usual normality properties. This test, then, is a unit-root test.⁵

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 summary statistics indicate that the 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 a lower risk premium 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.

The test statistic for the hypothesis that (P_{1t} , P_{2t}) drift apart over time is also an ADF statistic. The critical test value at the 1% level is -3.9001. In this test, which is a cointegration test, the residuals that comprise the u_t are replaced by the e_t from the estimated regression of equation (1). 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. In conjunction with the high adjusted- R^2 values, the statistics lead us to infer that both market pairs comprise substantially, if imperfectly, related markets.⁶

Moreover, the markets within each pair would appear to be slightly differentiated markets within a larger overall market. First, the estimate of $a_1 = 1.082$ for the Mid-C/COB regression and that of $a_1 = 1.093$ for the ComEd/Cinergy regression imply that a \$1 price change in either M_2 is accompanied by an approximately equal change in its companion M_1 . 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. Second, the estimate of $a_0 = -4.097$ for the Mid-C/COB regression and that of $a_0 = -5.010$ for the ComEd/Cinergy regression do in fact approximate the average cost of transmission between those market pairs.

Having rejected both null hypotheses, and in light of the goodness of fit of both estimated regressions, a power marketer may now feel comfortable in using those estimates to determine the optimal hedges and the forward-contract prices for either M_1 .

B. Empirical Results

The estimate of a_1 for either market pair suggests that approximately $Q = 1.1$ MW is the optimal number of MW to be purchased under the 12-month strip in M_2 for that pair of markets. The fact that $Q = 1.1$ regardless of the market pair is purely coincidental.

To determine the baseline price for each pair's M_1 forward contract we need the price of a 12-month strip in M_2 for that market pair. Using July 6, 1999 as a representative date, the Web site <WWW.POWERMARKETERS.COM> provided the information that we required: the price in COB on that date was \$35 per MWH; the price in Cinergy was \$39 per MWH. From the parameter estimates of Table 2, the baseline price in Mid-C/COB is then determined from equation (3) to be $F_B = -4.097 + 1.082 \times 35 = \33.77 per MWH. The baseline price in ComEd is similarly determined to be \$37.60 per MWH. The baseline prices are below the cost of the strips for each market pair because of the (negative) transmission cost approximated by the spot-price differentials reflected in the a_0 estimates of α_0 for each pair.

The residuals from each of the estimated regressions are used to compute the s^2 statistics for the basis risk that will determine the risk premium for that market pair. For Mid-C/COB, $s^2 = 7.4529$; for ComEd/Cinergy, $s^2 = 1521.0$. Tables 3 and 4 give the resulting risk premiums for forward contracts in Mid-C and ComEd, respectively, under various posited probabilities of a positive profit and desired frequencies of a positive profit. The tables also give the resulting on-peak forward price, computed as $F = F_B + \rho$. Thus, for example, if the power marketer marketing in Mid-C requires a 0.95 probability of an annual positive profit on the forward contract, it would set $\rho_a = 1.64(7.4529)^{0.5}(260)^{-0.5} = 0.28$. Then it would price the contract at $F = 33.77 + 0.28 = \$34.05$ per MWH. That power marketer's ConEd counterpart would price its forward contract at $F = 37.60 + 4.05 = \$41.65$ per MWH.

We would be remiss if we failed to comment, if only parenthetically, on the occasionally considerable differences in the forward-contract prices between the market

pairs. Specifically, even though COB and Cinergy have similar prices for their 12-month strips, the Mid-C contract prices are substantially below those for ComEd. These differences are occasioned by the large difference in risk premiums between the two markets. These large differences are the direct result of the previously mentioned large spot-price spikes in Cinergy/ComEd during the first two months of our sample period.

VI. CONCLUSIONS

Deregulation and open access to transmission networks have engendered energy markets with varying degree of maturity and liquidity. To compete for sales, power marketers often sell forward fixed-price contracts whose delivery is to be met by power purchases on the spot market. These marketers, however, must live with the inherently unpredictable vagaries of volatile spot-price markets. One clear option available to the marketers for dealing with those vagaries and the uncertain profit picture that they paint is for them to engage in cross hedging. The marketers cross hedge through strip contracts to purchase power in other markets whose spot prices move in sympathy with those in the market where the forward contracts are sold.

We have described a readily implemented approach through which the risk-averse marketer can determine both the optimal hedge and the energy price for the forward contract. That price is the sum of a baseline price and a risk premium, both of which will be gleaned through an estimated linear regression equation that relates the spot price in the forward-contract market to that in the market used for cross-hedging purposes. On the one hand, then, we have described a procedure that helps the power marketer to deal with spot-price uncertainty and to better understand and evaluate the consequences of any forward contract pricing policy that it adopts. On the other hand, we have set out a basic

framework that a forward-contract buyer should understand and be aware of so that it will be better positioned to negotiate with power marketers. In these regards we hope and believe that our paper can simultaneously serve and aid two masters whose interests necessarily conflict.

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NOTES

1. Anderson & Danthine (1981, p. 1184) remark that under certain not overly constraining conditions a hedging process can be equivalent to an expected-utility-maximizing process.
2. Although our approach is confined to hedging opportunities through energy markets with positively correlated prices, the opportunity to hedge exists so long as there is a non-zero correlation between the spot prices in the market served by the power marketer and the prices in the market(s) used for hedging purposes. The good(s) traded on the latter market(s) need not be electricity, and the price correlation(s) need not be positive (Anderson & Danthine, 1981).
3. The price, F , applied only to a flat block delivered to customers whose demands are fairly constant during on-peak hours. The power marketer would want to adjust F upward for a shaped block delivered to customers with spiky demands whose time profiles resemble those of local spot prices. The adjustment would reflect the effect of those spiky demands on the cost of the marketer's spot energy purchases.
4. The variance of the residuals is a sample variance. We are interested in the variance of the residuals for *any* day t in the universe of days. Thus for these purposes we want to compute an unbiased estimate of that variance as $\sum e_i^2 / (N - 1)$, where N is the number of days in the sample. For notational convenience, it will be assumed that s^2 is that unbiased estimate.
5. Both the unit-root test and the cointegration test that follows below for the second hypothesis are discussed in detail in Davidson & Mackinnon (1993 Chapter 20).

6. Market integration, as explored along these lines, is discussed in detail in Woo *et al.* (1997).

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
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."

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
ADF statistic for testing H ₀ : The two price series drift apart without limit	-6.92*	-11.53*

Notes: (a) "*" = "Significant at 1%." (b) The ADF statistic's critical value is -3.9001 at the 1% level.

Table 3. On-peak Forward Prices (\$/MWH) for Mid-C Based on COB's 12-Month Strip Price of \$35/MWH on 07/06/1999.

Base-line price	Desired frequency of positive profit	Desired probability of positive profit = 90%			Desired probability of positive profit = 95%			Desired probability of positive profit = 99%		
		Risk premium	Premium as % of baseline	On-peak forward Price	Risk premium	Premium as % of baseline	On-peak forward Price	Risk premium	Premium as % of baseline	On-peak forward Price
33.77	Daily	3.49	10.33%	37.26	4.47	13.24%	38.24	6.36	18.83%	40.13
	Monthly	0.62	1.84%	34.39	0.8	2.37%	34.57	1.14	3.38%	34.91
	Annually	0.22	0.65%	33.99	0.28	0.83%	34.05	0.4	1.18%	34.17

Table 4. On-peak Forward Prices (\$/MWH) for ComEd Based on Cinergy's 12-Month Strip Price of \$39/MWH on 07/06/1999.

Base-line price	Desired frequency of positive profit	Desired probability of positive profit = 90%			Desired probability of positive profit = 95%			Desired probability of positive profit = 99%		
		Risk premium	Premium as % of baseline	On-peak Forward Price	Risk premium	Premium as % of baseline	On-peak forward Price	Risk premium	Premium as % of baseline	On-peak forward Price
37.6	Daily	49.92	132.77%	87.52	64.00	170.21%	101.60	90.90	241.76%	128.50
	Monthly	11.27	29.97%	48.87	14.45	38.43%	52.05	20.52	54.57%	58.12
	Annually	3.16	8.40%	40.76	4.05	10.77%	41.65	5.76	15.32%	43.36