Designing Forward Markets for Electricity using Weather Derivatives*

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I. Introduction

Much of the discussion of contracts for electric power in restructured markets has been directed towards congestion rights on transmission lines. The discussion of congestion contracts has been driven to a large

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extent by the interests of suppliers of electricity. Most customers for electric power still pay fixed regulated rates, and as a result, have been protected from the risk of price volatility. Although the incumbent electric utilities do purchase electricity in the wholesale markets, there has been relatively little innovation on the demand side of the market. For example, regulators discouraged the utilities from using forward markets for electricity in California until the “meltdown” in 2000-2001. In New York State, some incumbent utilities discouraged the development of distributed energy resources, for example, because lower demand for electricity would undermine their ability to recover earnings for “stranded” assets during the transition to more competitive markets. Regardless of the reason for the lack of innovation in designing forward contracts, the transition periods with fixed rates are coming to an end for many customers. Hence, there is a growing need to develop new ways to deal with the risk faced by customers or their agents.

There are many examples of using weather variables as inputs in forecasting models for electricity (e.g., Taylor and Buizza, 2000; Smith, Roulston, and von Hardenberg, 2001). These papers use ensemble forecasting (multiple, and assumed equiprobable realizations of daily temperature patterns) to determine the degree of riskiness of load. Similar procedures have been used in Ning et al. (2001), although the stochastic basis for computing weather realizations is quite different (Wilks, 1999 and 2002). In addition, the potential for weather derivatives is clearly recognized in the energy industry as a way to hedge against both price and load volatility (Rookley, 2000). This is possible because the temperature is positively correlated with both load and price. In spite of this, weather derivatives still play a minor role and a recent text on
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energy derivatives has little discussion on the topic (Clewlow and Strickland, 2000). The approach in this paper is to 1) use the volatility of the return for a summer season as the metric for financial riskiness; 2) design forward contracts (pricing scheme) for purchasing (selling) electricity to strengthen market signals and 3) demonstrate the effectiveness of combining weather derivatives with forward contracts in a portfolio to reduce financial risk.

If high prices are more likely to occur on hot days when the load is high, then the spot market for power is very volatile. Assuming that a representative Distribution Company (DISCO) buys power in the spot market and sells to customers at a fixed rate $100/MWh set by regulators, then it is likely that losses will occur in many summers even though average returns are positive. The Generating Company (GENCO) faces similar volatility in the spot market.

There are two important problems with the standard forward contract, with a lump sum payment to the supplier and a relatively low fixed price. First, it may not reduce the overall average price when both parties benefit, and second, it effectively hides the high prices in the spot market when they occur. Consequently, the ability of market forces to mitigate high prices is undermined. The frequency of the high prices is the major determinant of the return in the spot market and the major source of risk to both the DISCO and the GENCO. 1) Since “hockey-stick” offers in real markets imply high price elasticities of supply in the high-price regime, price-responsive load can be a very effective way to lower prices (Mount, Schulze, Thomas and Zimmerman, 2001). Hence, it is

1) More rigorously speaking, upward spikes are always favorable to a GENCO and unfavorable to a DISCO.
sensible from the perspective of economic efficiency to ensure that
demand conservation is rewarded by substantial savings in costs. This
happens when customers have to pay the high prices.

The proposal made by Mount (2002) is to charge a high price for
peaking power on hot days in a forward contract and a low price for
baseload power. Hence, the high load on hot days is always expensive.
This contract is not attractive on its own, particularly to the DISCO,
because the total cost of purchasing power is still very volatile. However,
the associated increase of risk can be hedged by a weather derivative
based on the number of hot days in the summer. In this paper, the form
of contract is modified to charge high prices for all purchases on hot
days and a low price for purchases on other days. It shows that all risk
can be hedged effectively and that both the DISCO and the GENCO
benefit from the combined contracts. It argues further that a conventional
Cooling-Degree-Day(CDD) Weather derivative is not very effective for
hedging directly against purchases in the spot market.

The main modification to a typical weather derivative based on CDD is
that the payout is based on the number of hot days using a collar
contract. Customers pay if the number of hot days is below average (the
strike value) and receive payments if the number of hot days is above
average. The main modification to typical forward contracts is that a
high price is paid on every hot day and a low price on other days.
Consequently, the positive correlation between the weather derivative and
the contract price is much higher than the correlation with the actual
spot price, because high spot prices occurred only 60% of the time on
hot days during the summer of 1999 in the PJM market.

In Mount (2002), however, all risks come from the number of hot days
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during a summer. In addition, there are two types of load and spot price, depending upon whether it is a hot day or a cool day. In order to be more accurate and realistic in analyzing the cost of buying electric power during a summer, more realistic models for temperature, load, and spot price are needed. The risk that both the DISCO and the GENCO encounter over a summer season is the cost (or revenue) risk, consisting of both price and volumetric risks. Using models for load and spot price, the risk from cost or revenue can be analyzed. In this paper, using the WGEN model for temperature process (Briggs and Wilks, 1996; Wilks, 1999 and 2002), ARMA (3,1) for load, and the regime switching model with time varying transition probabilities for spot price, this paper develops forward contracts for electricity that stabilize the total cost of purchases over a summer.

This paper is organized as follows. In section II, the relationships between temperature, load, and spot price are explored using data for 1999−2001 in the PJM (Pennsylvania−New Jersey−Maryland) wholesale electricity market. In section III, more realistic models for the temperature, load, and price are briefly introduced from previous researches. In section IV, performances of different types of forward contracts are compared. This section shows how forward contracts for buying power can reduce the financial risk of the cost of buying power during a summer. In section V, the forward contract combined with an appropriate weather collar option reduces the volatility of the cost substantially. In section VI results of the above analyses are summarized and several conclusions are suggested.
The relationship between temperature and the demand (load) for electricity is well understood (Ramanathan \textit{et al.}, 1997; Bunn, 1999, 2000). Using relatively simple forms of ARIMA models (Box and Jenkins, 1976), it is possible to predict the daily maximum load for PJM with a 1~2% forecasting error using temperature as an input variable (Ning, 2001). An innovation of previous researches (Ethier, 1999; Ethier and Mount, 1999) was to predict the daily price of electricity (average for the sixteen-hour peak) using a regime switching model (Hamilton, 1994). One regime has a low average price with a small variance and the other has a high average price with a large variance. The probabilities of switching from one regime to another are determined by Markov probabilities. This model was extended to include load or forecasted load as an explanatory variable (Ning, 2001; Ning, Mount and Wilks, 2001). In particular, the probability of switching to the high price regime (i.e., observing a price spike) is positively related to the load, and therefore, also to temperature in the summer. Nevertheless, the probability of getting a price spike is only about 60% for PJM in the summer of 1999 at the highest load. Hence, the predictability of individual price spikes is relatively low compared to the predictability of load.

In Yoo (2004a, 2004b), the predictability of price spikes is enhanced by adding the temperature as an explanatory variable in transition probability equations. The transition probabilities show very clear threshold effect that the switching probability to the high price regime is up to 1. The price spike behavior very clearly depends upon the weather patterns.
Spikes occur more frequently during a warm summer than a cool summer. These spikes change the shape of the density of the summer cost of buying electric power to shift and to be skewed substantially toward right (see <Figure 1>). This implies that the warm summer can increase very sharply the cost of buying electric power in the wholesale market so that the utility company may be put into the default risk. Some important findings from correlations in Yoo (2004b) are that some weather-related contracts may help to hedge against these weather-related risks in the cost of buying electricity and that weather-related contracts may be more effective to hedge against the aggregate risk of the cost during a summer than daily variation of the cost.

In terms of the bidding behavior of suppliers, most capacity is offered at prices less than $50/MWh, but a few units are offered at prices up to $1000/MWh. This kind of bidding behavior ends up with a
<Figure 2> Daily Maximum Load and On-peak Spot Price in PJM (1999-2001)

<Figure 3> Daily Maximum Load and Average Temperature in PJM
“hockey-stick” shaped supply curve, which causes price spikes. Price spikes are anathema to regulators, and complicated procedures for suppressing price spikes have been introduced in most restructured markets. These efforts tend to reduce the effectiveness of price signals as a way to discipline markets (i.e., by reducing or shifting load and increasing supplies when price spikes occur). The basic objective of the new research project is to demonstrate that it is possible to hedge against high prices, and therefore, to allow price signals to work effectively.

<Figure 2> and <Figure 3> show the strong relationships between the daily temperature (Philadelphia) and the loads in PJM for 1999, 2000 and 2001. <Figure 4> shows the corresponding weak relationships between temperature and the average on-peak spot prices. Since most price spikes
occur in the summer months, the focus in this paper is on the price and volume risk during the summer months.

(Table 1) gives some summary statistics for temperature, load and price for three summers in PJM. The correlations between load and temperature are about 0.9 in the two hot years and lower in the cool year (2000). The correlations between price and temperature are much lower, and the lowest correlation occurs in 1999 when prices are high. This is also true for the correlations between load and price. These statistics support the conventional belief that temperature derivatives are effective hedges against volume risk but not against price risk.

The plots in (Figure 4) suggest that high prices are associated with hot days, but the probability of getting a high price on a hot day is much less than one. Each summer corresponds to the 92 days in June, July and August. Temperature is the daily average for each summer ((Maximum + Minimum)/2), cooling degree days(CDD) is the cumulative
value of the amount of temperature over 65°F, i.e.,
\[ CDD = \sum_{i=1}^{n} \max(T_i - 65, 0), \]
where \( T_i \) is a daily average temperature at date \( i \).

The number of hot days is the cumulative number of days when the
daily average temperature is greater than or equal to 80°F, i.e.,
\[ HD = \sum_{i=1}^{n} I(T_i \geq 80), \]

### III. Models and Assumptions

To describe the spot market for electricity realistically, accurate models
for temperature, load, and spot price are needed. In addition, the risk in
the cost of purchasing electricity during a summer consists of both price
and volumetric risks, which are affected by the weather uncertainty.

The temperature paths in Philadelphia are generated for each type of
summer by WGEN (Wilks, 2002; Yoo, 2004b). Both daily average and
maximum loads are estimated using an ARMA (3,1) model (Yoo, 2004b).
A regime switching model with time-varying transition probabilities is
estimated to describe the behavior of the spot price (Yoo, 2004a, 2004b).
The daily cost for the 16 on-peak hours is calculated by the product of
16 hours times on-peak average load times spot price. The total cost of
purchases over a summer is defined as a sum of daily costs during a
summer. For each type of summer, three thousand paths of summer
temperature, load, and spot price are generated.

For a customer, the daily variability of costs is not as important as the
variability of the monthly bill. This same argument applies to the
Distribution Company (DISCO) supplying the customer. Hence, it is not necessary to hedge against daily variability in costs to meet reasonable financial goals. In the following analysis, the chosen criterion is the total cost of supplying power for a summer, consisting of 92 days. The objective of the analysis is to evaluate the effectiveness of different types of forward contracts as ways of reducing uncertainty about the total cost of purchasing power for the summer.

For simplicity, it is assumed that a representative DISCO buys power in the spot market from two types of representative Generation Company (GENCO) and that the DISCO sells to customers at a fixed rate set by regulators.

One type of GENCO, called GENCO1, serves baseload power and the other type, called GENCO2, serves peak load that is specified to be above 35GWh. The variable cost of GENCO1 is assumed to be $30/MWh and that of GENCO2 $80/MWh. The load sharing rule between the two GENCOs is specified as follows:

\[
\begin{align*}
    da_1 &= \begin{cases} 
    35 \text{GWh} & \text{if } da_t \geq 35 \text{GWh and } sp_t \geq 80 \text{ /MWh,} \\
    da_t & \text{otherwise,}
    
    da_2 &= \begin{cases} 
    da_t - 35 \text{GWh} & \text{if } da_t \geq 35 \text{GWh and } sp_t \geq 80 \text{ /MWh,} \\
    da_t & \text{otherwise,}
    \end{cases}
    \end{align*}
\]

where, \( da_t \) is the daily on-peak average load, \( da_1 \), the load served by GENCO1, \( da_2 \), by GENCO2, and \( sp_t \), the load-weighted on-peak spot price.

It is obvious that the DISCO and the GENCO will accept a forward contract only if both benefit. So any forward contract should meet this incentive compatibility condition. It is assumed that a regulator plays the
role of transferring a lump sum amount to equalize the means of each forward contract so that both the GENCO and the DISCO will accept the forward contract if the variance of the forward contract is less than the variance of purchasing at the spot price. It is assumed for simplicity that both the GENCO and the DISCO have continuous concave Bernoulli utility functions that depend on the monetary return. For the GENCO, the cost of purchasing power by the DISCO corresponds to the revenue received by the GENCO, and the GENCO faces the associated uncertainty.

There are two underlying assumptions being made in the following analysis. The first is that both the DISCO and GENCOs have the same knowledge about the spot market. In other words, the characteristics described in this section represent the beliefs of the DISCO and GENCOs about the next summer and determine their willingness to execute a forward contract. The second assumption is that neither the DISCO or the GENCO can influence the spot market by making a forward contract. If high prices are caused by using market power, holding firm contracts would limit this behavior and lower average prices. Hence, this important interaction between spot price behavior and forward contracts is not addressed in this paper.

These assumptions make the relationship between the GENCO and the DISCO different from the von Stackelberg game with the GENCO as the leader in Wu, Kleindorfer and Zhang (2002). In Wu et al. (2002), however, when the risk factor is zero, the GENCO faces a risky spot market and its revenue relies entirely on the forward contract.2) So our assumptions

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2) The risk factor is defined as a percentage of the leader GENCO’s residual output that is sold in the spot market. This risk factor provides the incentive for the GENCO to sign a forward contract with the DISCO.
can be interpreted to mean that the GENCO may encounter an extremely risky spot market and decide to sell all the electric power in the forward market.

**IV. Trading using Forward Contracts**

In this section, several types of the forward contract are considered, and the means of all types of contract are adjusted to be the same as the mean with no forward contract through transferring a lump sum payment. So based on relative riskiness, a forward contract with a smaller standard deviation of the return is preferred. Since the primary concern is to compare the performances of different types of forward contract, the equilibrium forward price is assumed to be given.\(^3\)

As a base case, no forward contract is considered (Contract 1). Under contract 1, all the electric power is traded in the spot market:

\[ p_1 = \text{spot price.} \]

The regulated tariff assumes that forward price is $100/MWh (Contract 2):

\[ p_2 = 100\$/\text{MWh}. \]

The standard supplier assumes that the forward price is $30/MWh (Contract 3):

\[^3\) For the equilibrium forward price and contract position, see Bessembinder and Lemmon (2002) and Mount (2002).\]
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<Table 2> The STD of the Return under Forward Contracts ($Mill/Summer)

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>DISCO</th>
<th>GENCO1</th>
<th>GENCO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract</td>
<td>1,062</td>
<td>911</td>
<td>232</td>
</tr>
<tr>
<td>2. Regulated Tariff</td>
<td>0</td>
<td>66</td>
<td>10</td>
</tr>
<tr>
<td>3. Standard Supplier</td>
<td>94</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>4. Hot Day Pricing</td>
<td>461</td>
<td>499</td>
<td>28</td>
</tr>
<tr>
<td>5. CDD Pricing</td>
<td>706</td>
<td>713</td>
<td>81</td>
</tr>
<tr>
<td>Mean</td>
<td>1,044</td>
<td>1,994</td>
<td>338</td>
</tr>
</tbody>
</table>

\[ p_3 = 30\$/MWh. \]

For hot day (HD) contract (Contract 4), called "hot-day pricing," the forward price is set to $200/MWh for a hot and week day, and $50/MWh otherwise:

\[ p_4 = \begin{cases} 
200 /\text{MWh} & \text{for a hot and week day,} \\
50 /\text{MWh} & \text{otherwise.} 
\end{cases} \]

The CDD contract (Contract 5), called "CDD pricing," assumes that the forward price is $30/MWh plus the daily CDD times the tick price of $10/MWh, and $30/MWh for the case where the daily CDD is zero:

\[ p_5 = \begin{cases} 
[30 + (T_i - 65) \times 10] /\text{MWh} & \text{for } T_i > 65 \\
30 /\text{MWh} & \text{for } T_i \leq 65 
\end{cases} \]

where \( T_i \) is the temperature on day \( i \).

<Table 2> summarizes the means and standard deviations (STD) of the returns for the five different contracts. All the means are the same as
those of Contract 1 through transferring the appropriate lump sum payment. Volatilities of the return in the spot market are larger than volatilities resulting from other contracts for the DISCO and the two GENCOs. All other kinds of the forward contracts have smaller variabilities of the return than the spot market (Contract 1).

Even though Contracts 2 (100$/MWh) and 3 (30$/MWh) with fixed prices have smaller volatilities than other contracts, they have a crucial flaw: they remove the market signal when load is high so that inefficiency may occur. For example, even though the price spikes are the primary cause of the financial problems for a DISCO in the spot market, paying a lower price when price spikes occur undermines the market incentives for reducing demand and increasing supply. Hence, forward contracts may effectively neutralize the forces needed to bring discipline to the market and lower prices in the future.

This problem is closely related to the events in the Californian market in 2000–2001. High prices in the spot market make it possible for suppliers to get attractive forward contracts. Buyers will still pay prices that are higher than they would be in a truly competitive market. This is a genuine predicament for regulators. It may be true that having a large proportion of demand covered by forward contracts will lower spot prices, as many people have argued in California. However, these low prices will not benefit customers if high prices are still being paid under the contracts. What is needed is a way to hedge against paying high prices without losing the incentives that high prices provide in a market. The goal of regulators should be to help customers maintain financial viability in spite of paying high prices occasionally. This strategy is very different from the approach favored by the Federal Energy Regulatory Commission.
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(FERC) and many state regulators. Current regulatory interventions, such as the soft cap auction proposed by the FERC for California in December 2000, try to reduce the effects of high prices. In contrast, the discipline of a market implies that suppliers who try to be greedy by offering capacity at high prices should lose market share. Making the load responsive to high prices, for example, is one way to bring more discipline to a market.

Although the volatilities from HD and CDD pricing schemes are less than the volatility from the spot market, they are still very volatile. Such volatilities result from the uncertainty of the number of hot days or cooling degree days for a summer season, which are the main source of risk in the electricity market. However, these contracts preserve more accurate price signals when the load is high and the temperature increases. The uncertainty or risk associated with the number of hot day or CDD can be hedged using a corresponding weather derivative. Under the HD pricing or the CDD pricing, the forward prices are perfectly correlated with hot days or daily CDD, respectively. This implies that it is easier to hedge against price risks under forward contracts than in the spot market. In the spot market, for example, high prices can occur on cool days as well as on the majority of hot days, and as a result, a weather option cannot provide a perfect hedge against high prices. In contrast, the high prices under hot-day pricing are paid on every hot day and never paid on cool days. Therefore, HD and CDD pricing schemes combined with appropriate weather derivatives are more desirable.
V. A Potential Role for Weather Derivatives

Even though the HD and CDD pricing schemes preserve price signals, the volatilities of the returns are still high and there is a lot of room for reducing the volatilities by using appropriate weather derivatives. In this section, two types of weather derivative are considered: HD and CDD collar options, based on the number of hot days (HD) and cooling degree days (CDD) during a summer, respectively. These options have the aggregate property of a path-dependent Asian option.

The HD collar option pays (costs) when there are more (less) hot days than the strike level of number of hot days. Its payout is determined as follows:

\[
\text{Payout}_{HD} = T_{HD} \times (\text{HD} - K_{HD}),
\]

where \( K_{HD} \) is the strike level and is set to the sample mean of the number of hot days (see Table 3). The level of tick \( T_{HD} \) is determined to minimize the standard deviation of the combined return during a summer under a given contract for electricity. The CDD collar option pays (costs) when there are more (less) CDD than the strike level of CDD. Its payout is determined as follows:

\[
\text{Payout}_{CDD} = T_{CDD} \times (\text{CDD} - K_{CDD}),
\]

where \( K_{CDD} \) is the strike level of CDD and is set to the sample mean of CDD (see Table 3). The level of tick \( T_{CDD} \) is determined as the level
that minimizes the standard deviation of the return during a summer under a given contract.

In both cases, the performance of the weather derivatives depends on the correlations between the revenues of different pricing rules and the underlying weather indices (see <Table 4>).
1. DISCO and GENCO1 (Baseload)

The means and standard deviations (STD) of the returns for the DISCO and GENCO1 from the forward contracts combined with appropriate collar options are listed in <Table 6> and <Table 8>, respectively, and the tick values are listed in <Table 5> and <Table 7>. Forward contracts combined with weather derivatives reduce drastically the volatility of the returns under forward contracts. The volatilities of the revenues from the fixed forward contracts (Contracts 2 and 3) and CDD pricing (contracts) are reduced more by combining with the CDD collar options than by the HD collar options. This is because the financial risk that comes from the volume risk is hedged better by the CDD collar options. The CDD has a higher correlation with load than the HD does.

The HD collar option is a better hedge against the risk of spot pricing and HD pricing (contracts 1 and 4). This result is consistent with the observation that the HD option has higher correlations with the revenue from Contracts 1 and 4 than the CDD option does (see <Table 4>). Under HD pricing, the HD collar option outperforms the CDD collar option for reducing the volatility (see <Figure 5>, <Figure 6>, <Figure 12> and <Figure 13>). Under HD pricing, specifying a high price for hot days and a lower price for other days is inherently risky, but this risk can be offset effectively by an appropriate collar option for hot days because the forward price of the HD pricing is perfectly correlated with the number of hot days. However, this HD collar option cannot perfectly hedge against the volumetric risk because the number of hot days is not closely correlated with the load.
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〈Table 5〉 The Tick Size for Different Contracts ($Mill): DISCO

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract</td>
<td>6.5</td>
<td>110</td>
</tr>
<tr>
<td>2. Regulated Tariff</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. Standard Supplier</td>
<td>0.8</td>
<td>10.8</td>
</tr>
<tr>
<td>4. Hot Day Pricing</td>
<td>3</td>
<td>56.9</td>
</tr>
<tr>
<td>5. CDD Pricing</td>
<td>5.8</td>
<td>82.8</td>
</tr>
</tbody>
</table>

〈Table 6〉 The STD of the Return under Different Combined Contracts ($Mill/Summer): DISCO (STD from 〈Table 2〉 in the parentheses)

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract (1,062)</td>
<td>637</td>
<td>716</td>
</tr>
<tr>
<td>2. Regulated Tariff (0)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. Standard Supplier (94)</td>
<td>42</td>
<td>9</td>
</tr>
<tr>
<td>4. Hot Day Pricing (461)</td>
<td>137</td>
<td>276</td>
</tr>
<tr>
<td>5. CDD Pricing (706)</td>
<td>299</td>
<td>78</td>
</tr>
</tbody>
</table>

〈Table 7〉 The Tick Size for Different Contracts ($Mill): GENC01

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract</td>
<td>5.9</td>
<td>98.1</td>
</tr>
<tr>
<td>2. Regulated Tariff</td>
<td>0.5</td>
<td>6.7</td>
</tr>
<tr>
<td>3. Standard Supplier</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. Hot Day Pricing</td>
<td>3.5</td>
<td>62.4</td>
</tr>
<tr>
<td>5. CDD Pricing</td>
<td>5.9</td>
<td>82</td>
</tr>
</tbody>
</table>

〈Table 8〉 The STD of the Return under Different Combined Contracts ($Mill/Summer): GENC01 (STD from 〈Table 2〉 in the parentheses)

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract (911)</td>
<td>506</td>
<td>560</td>
</tr>
<tr>
<td>2. Regulated Tariff (66)</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>3. Standard Supplier (0)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. Hot Day Pricing (499)</td>
<td>130</td>
<td>262</td>
</tr>
<tr>
<td>5. CDD Pricing (713)</td>
<td>328</td>
<td>42</td>
</tr>
</tbody>
</table>
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〈Table 9〉 The Tick Size for Different Contracts ($Mill): GENCO2

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract</td>
<td>1.1</td>
<td>19.8</td>
</tr>
<tr>
<td>2. Regulated Tariff</td>
<td>0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>3. Standard Supplier</td>
<td>0.2</td>
<td>2.9</td>
</tr>
<tr>
<td>4. Hot Day Pricing</td>
<td>0.1</td>
<td>2.4</td>
</tr>
<tr>
<td>5. CDD Pricing</td>
<td>0.5</td>
<td>8.7</td>
</tr>
</tbody>
</table>

〈Table 10〉 The STD of the Return under Different Combined Contracts ($Mill/Summer): GENCO2 (STD from 〈Table 2〉 in the parentheses)

<table>
<thead>
<tr>
<th>Forward Contract</th>
<th>HD</th>
<th>CDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Contract (232)</td>
<td>142</td>
<td>157</td>
</tr>
<tr>
<td>2. Regulated Tariff (10)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3. Standard Supplier (26)</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>4. Hot Day Pricing (28)</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>5. CDD Pricing (81)</td>
<td>46</td>
<td>53</td>
</tr>
</tbody>
</table>

The advantage of combining a forward contract with a weather derivative is that the high prices on hot days, or when the temperature is high, reflect the underlying high cost of producing power when the load is high. This market signal will encourage customers to conserve and generators to increase supplies. For customers, using less power on hot days, or when the temperature is high, will reduce their bills substantially. The net payment from the HD or CDD options would be allocated fairly to each class of customers on a predetermined basis, and participation could be voluntary. Another finding is that CDD pricing combined with a CDD collar option has a lower volatility than HD pricing with a HD collar option because CDD is highly positively correlated with both the volume (load) and the contract price.
2. GENCO2 (Peak Unit)

The tick size for the five combined contracts and the STD of the returns of GENCO2 from the forward contracts combined with appropriate collar options are listed in <Table 8> and <Table 9>, respectively. For GENCO2 that serves the peak load over 35GW, the combined contracts with the HD collar option work better in all five cases than those with the CDD collar option. The volatility of GENCO2’s revenue reflects the spike behavior of the spot price and the non-linear behavior of the peak load. Under all five contracts, the HD collar option more effectively reduces the volatility than the CDD collar option (<Figure 17>~<Figure 18>).

VI. Conclusion

The objective of this paper is to show how weather derivatives can be used to strengthen the position of buyers of electric power in restructured wholesale markets for electricity. The spot market for electric power can be simulated realistically using WGEN for the temperature, an ARMA (3,1) for the load, and a regime switching model for the spot price.

Even though forward contracts with fixed prices have smaller volatilities than other contracts, they have a crucial flaw. They remove the market signal of a high price when the load is high so that the inefficiency may occur.

HD and CDD pricing schemes preserve some of the correct price signals, but the volatilities of the combined return are high and there is
room for reducing the volatilities by using appropriate weather derivatives. The results show that correct market signals can be preserved in a contract and the associated financial risk can be offset by weather options. The advantage of combining a forward contract with a weather derivative is that the high prices on hot days, or when the temperature is high, reflect the underlying high cost of producing power when the load is high. The combined contract with a weather derivative substantially reduces the volatility the return.

For a DISCO and GENCO1 that serves the baseload, it turns out that the CDD pricing combined with a CDD collar option has a lower volatility than HD pricing with a HD collar option because CDD is highly positively correlated with the load and perfectly correlated with the CDD contract price. For GENCO2 that serves the peak load over 35GW, combined contracts with the HD collar option work better than those with the CDD collar option in all five cases. This is because the volatility of GENCO2’s revenue reflects the spike behavior of the spot price and the non-linear behavior of the peak load.

A final point, which is very important for policy considerations, is that the combined forward contract with a weather option does not solve the problem of high prices in the short run. It is highly unlikely that a GENCO will settle for a contract with a lower average price than the spot market even if this latter price is much higher than competitive levels. The advantage of the combination contract is that the market incentives of paying high prices on hot days or when the temperature is high are not lost. If demand is reduced on a hot day or when the temperature is high, the savings to a DISCO (or to customers if they pay actual costs) will be relatively large. It will also provide better security
for recovering investments in new peaking capacity and demand conservation. At the present time, price spikes are treated by many regulators as an aberration. Their goal is to suppress price spikes. A better strategy is to insure against the financial losses associated with price spikes. Combining weather options with forward contracts is an effective way to hedge against high prices. More importantly, this strategy strengthens the powerful forces that make markets work competitively. Even in a truly competitive market, it is expensive to meet high loads on hot days or when the temperature is high, because the capacity factors on some peaking units are very low making it difficult to cover all costs. Customers or their agents should be made more aware of this fact, and, at the same time, be protected from the financial consequences.

(Figure 5) The STD of DISCO's Return under Forward Contracts
($\text{Mill/Summer}$)

1. Spot market: std=1062

2. Regulated tariff: std=0

3. Standard supplier: std=0
(Figure 6) The STD of DISCO’s Return under Spot Market and HD Collar Option ($Mill/Summer)

1. Spot market: std = 1062
2. HD Payout: std = 849
3. Spot market + HD Collar option: std = 619

(Figure 7) The STD of DISCO’s Return under Spot Market and CDD Collar Option ($Mill/Summer)

1. Spot market: std = 1062
2. CDD Payout: std = 784
3. Cool, Normal, Warm summer
4. Spot market + CDD Payout: std = 716
(Figure 8) The STD of DISCO's Return under HD Pricing and HD Collar Option ($Mill/Summer)

1. Spot market: std = 1062
2. 4. Hot Day pricing: std = 461
   HD Payout: std = 440
3. Cool Normal Warm Summer
4. Hot Day pricing + HD Payout: std = 137

(Figure 9) The STD of DISCO's Return under CDD Pricing and CDD Collar Option ($Mill/Summer)

1. Spot market: std = 1062
2. 5. CDD pricing: std = 706
   CDD Payout: std = 701
3. Cool Normal Warm Summer
4. CDD pricing + CDD Payout: std = 78
(Figure 10) The STD of GENCO1’s Return under Forward Contracts ($Mill/Summer)

1. Spot market: std=911
2. Regulated tariff: std=66
3. Standard supplier: std=0

(Figure 11) The STD of GENCO1’s Return under Spot Market and HD Collar Option ($Mill/Summer)

1. Spot market: std=911
2. HD Payout: std=757
3. Spot market + HD Payout: std=506
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〈Figure 12〉 The STD of GENCO1’s Return under Spot Market and CDD Collar Option ($Mill/Summer)

〈Figure 13〉 The STD of GENCO1’s Return under HD Pricing and HD Collar Option ($Mill/Summer)
<Figure 14> The STD of GENCO1's Return under CDD Pricing and CDD Collar Option ($Mill/Summer)

1. Spot market: std=911

5. CDD Pricing: std=713

CDD Payout: std=712

Cool Normal Warm Summer

CDD pricing + CDD Payout: std=42

<Figure 15> The STD of GENCO2's Return under Forward Contracts ($Mill/Summer)

1. Spot market: std=232

2. Regulated tariff: std=10

Cool Normal Warm Summer

3. Standard supplier: std=26
Figure 16  The STD of GENCO2's Return under Spot Market and HD Collar Option ($Mill/Summer)

Figure 17  The STD of GENCO2's Return under Spot Market and CDD Collar Option ($Mill/Summer)
(Figure 18) The STD of GENCO2's Return under HD Pricing and HD Collar Option ($Mill/Summer)

1. Spot market: std = 232
2. HD pricing: std = 28
3. HD payout: std = 19
4. Cool Normal Warm Summer
5. HD pricing + HD Payout: std = 20

(Figure 19) The STD of GENCO2's Return under CDD Pricing and CDD Collar Option ($Mill/Summer)

1. Spot market: std = 232
2. Cool Normal Warm Summer
3. 5. CDD pricing: std = 81
4. CDD payout = 62
5. CDD pricing + CDD Payout: std = 53

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Designing Forward Markets for Electricity using Weather Derivatives


요 약

날씨파생상품을 이용한 전기선물시장 설계

유 시 용

본 논문은 날씨파생상품이 전기도매시장에서의 가격 및 수량 위험의 헤지수단으로서 활용될 수 있다는 것을 보여주고 있다. 또한 일별 수준의 가격과 물량이 아니라 여름기간 동안의 전기도매시장에서의 전기구입 비용 혹은 전기판매 수입을 대상으로 하여 날씨관련 계약형태의 위험헤지효과를 살펴보았다. 날씨관련 계약들이 전기도매시장의 시장신호를 더 잘 보전하고 있으며, 도매전기 구입관련 금융위험을 더 잘 해지함을 발견하였다. 전기 도매시장에서 선물계약과 날씨파생상품을 결합하였을 경우, 더운 날의 경우 높은 전기생산비용이 가격에 반영되며, 전기판매 수입 혹은 전기구입 비용의 변동성이 현저히 낮아진다는 것을 발견하였다.

주제어: 날씨파생상품, 위험관리, Hot Day 가격확정, CDD 가격확정, 전기선도시장
This paper shows how weather derivatives can be used to hedge against the price risk and volume risk of purchasing relatively large amounts of electricity. Our specific approach to designing new contracts for electricity is to focus on the return over a summer season rather than on the daily levels of demand and price. It is shown that correct market signals can be preserved in a contract and the associated financial risk can be offset by weather options. The advantage of combining a forward contract with a weather derivative is that the high prices on hot days or when the temperature is high reflect the underlying high cost of producing power when the load is high and that the combined contract with a weather derivative substantially reduces the volatility of the return.

Keywords: Weather Derivatives, Risk Management, Hot Day Pricing, CDD Pricing, Electricity Forward Market