Energy Markets III: Weather Derivates

René Carmona

Bendheim Center for Finance
Department of Operations Research & Financial Engineering
Princeton University

Banff, May 2007
Weather and Commodity

- **Stand-alone**
  - temperature
  - precipitation
  - wind

- **In-Combination**
  - natural gas
  - power
  - heating oil
  - propane

- Agricultural risk (yield, revenue, input hedges and trading)

- Power outage - contingent power price options
For many contracts, delivery needs to match demand

**Demand** for energy highly correlated with **temperature**
- Heating Season (winter) HDD
- Cooling Season (summer) CDD

**Stylized Facts** and **First (naive) Models**
- Electricity demand = $\beta \times \text{weather} + \alpha$
  - Not true all the time
  - Time dependent $\beta$ by filtering!
- From the stack: Correlation (Gas,Power) = f(weather)
  - No significance, too unstable
  - Could it be because of heavy tails?

**Weather dynamics** need to be included
- **Another Source of Incompleteness**
Hedging Volume Risk
- Protection against the Weather Exposure
  - Temperature Options on CDDs (Extreme Load)

Hedging Basis Risk
- Protection against Gas & Electricity Price Spikes
- Gas purchase with Swing Options
Hedging Volume Risk
- Protection against the Weather Exposure
- **Temperature Options** on CDDs (Extreme Load)

Hedging Basis Risk
- Protection against Gas & Electricity Price Spikes
- Gas purchase with **Swing Options**
Hedging Volume Risk
- Protection against the Weather Exposure
- **Temperature Options** on CDDs (Extreme Load)

Hedging Basis Risk
- Protection against Gas & Electricity Price Spikes
- Gas purchase with **Swing Options**
Hedging Volume Risk
- Protection against the Weather Exposure
- **Temperature Options** on CDDs (Extreme Load)

Hedging Basis Risk
- Protection against Gas & Electricity Price Spikes
- Gas purchase with **Swing Options**
Hedging Basis Risk

- Use **Swing Options**
- Multiple Rights to deviate (within bounds) from base load contract level
- **Pricing & Hedging** quite involved!
  - Tree/Forest Based Methods
    - Direct Backward Dynamic Programing Induction (à la Detemple-Jaillet-Ronn-Tompaidis)
  - New Monte Carlo Methods
    - Nonparametric Regression (à la Longstaff-Schwarz) Backward Dynamic Programing Induction
Use **Swing Options**

Multiple Rights to deviate (within bounds) from base load contract level

**Pricing & Hedging** quite involved!

- Tree/Forest Based Methods
  - Direct Backward Dynamic Programing Induction (à la Detemple-Jaillet-Ronn-Tompaidis)

- **New Monte Carlo Methods**
  - Nonparametric Regression (à la Longstaff-Schwarz) Backward Dynamic Programing Induction
Review: **Classical Optimal Stopping Problem: American Option**

- $X_0, X_1, X_2, \cdots, X_n, \cdots$ rewards
- Right to ONE Exercise
- Mathematical Problem

\[
\sup_{0 \leq \tau \leq T} \mathbb{E}\{X_\tau\}
\]

**Mathematical Solution**

- Snell’s Envelope
- Backward Dynamic Programming Induction in Markovian Case

*Standard, Well Understood*
Review: Classical Optimal Stopping Problem: American Option

- $X_0, X_1, X_2, \ldots, X_n, \ldots$ rewards
- Right to ONE Exercise
- Mathematical Problem

$$\sup_{0 \leq \tau \leq T} \mathbb{E}\{X_\tau\}$$

Mathematical Solution

- Snell’s Envelop
- Backward Dynamic Programming Induction in Markovian Case

*Standard, Well Understood*
In its simplest form the problem of **Swing/Recall** option pricing is an

**Optimal Multiple Stopping Problem**

- $X_0, X_1, X_2, \ldots, X_n, \ldots$ rewards
- Right to $N$ Exercises
- Mathematical Problem

$$\sup_{0 \leq \tau_1 < \tau_2 < \cdots < \tau_N \leq T} \mathbb{E}\{X_{\tau_1} + X_{\tau_2} + \cdots + X_{\tau_N}\}$$

- **Refraction** period $\theta$

$$\tau_1 + \theta < \tau_2 < \tau_2 + \theta < \tau_3 < \cdots < \tau_{N-1} + \theta < \tau_N$$

Part of recall contracts & crucial for continuous time models
Instruments with Multiple American Exercises

- **Ubiquitous in Energy Sector**
  - Swing / Recall contracts
  - End user contracts (EDF)

- **Present in other contexts**
  - Fixed income markets (e.g. chooser swaps)
  - Executive option programs
    - Reload → Multiple exercise, Vesting → Refraction, ···
  - Fleet Purchase (airplanes, cars, ···)

- **Challenges**
  - Valuation
  - Optimal exercise policies
  - Hedging
Instruments with Multiple American Exercises

- **Ubiquitous in Energy Sector**
  - Swing / Recall contracts
  - End user contracts (EDF)

- **Present in other contexts**
  - Fixed income markets (e.g. chooser swaps)
  - Executive option programs
    - Reload → Multiple exercise, Vesting → Refraction, · · ·
  - Fleet Purchase (airplanes, cars, · · ·)

- **Challenges**
  - Valuation
  - Optimal exercise policies
  - Hedging
Instruments with Multiple American Exercises

- Ubiquitous in Energy Sector
  - Swing / Recall contracts
  - End user contracts (EDF)
- Present in other contexts
  - Fixed income markets (e.g. chooser swaps)
  - Executive option programs
    - Reload $\rightarrow$ Multiple exercise, Vesting $\rightarrow$ Refraction, $\cdots$
  - Fleet Purchase (airplanes, cars, $\cdots$)
- Challenges
  - Valuation
  - Optimal exercise policies
  - Hedging
Exercise regions for $N = 5$ rights and finite maturity computed by Malliavin-Monte-Carlo.
Princeton University Electricity Budget

2.8 M $ over (PU is small)

- The University has its own Power Plant
- Gas Turbine for Electricity & Steam

Major Exposures

- Hot Summer (air conditioning) Spikes in Demand, Gas & Electricity Prices
- Cold Winter (heating) Spikes in Gas Prices
Never Again such a Short Fall !!!

Student (Greg Larkin) Thesis

**Hedging Volume Risk**
- Protection against the Weather Exposure
- *Temperature Options* on CDDs (Extreme Load)

**Hedging Basis Risk**
- Protection against Gas & Electricity Price Spikes
- Gas purchase with *Swing Options*
Average Daily Load against Average Daily Temperature (PJM data).
The Need for Temperature Options

- Rigorous Analysis of the Dependence between the Shortfall and the Temperature in Princeton
- Use of Historical Data (sparse) & Definition of a \textit{Temperature} Protection
  - Period of the Coverage
  - Form of the Coverage
- Search for the Nearest Stations with HDD/CDD Trades
  - La Guardia Airport (LGA)
  - Philadelphia (PHL)
- Define a Portfolio of LGA & PHL forward / option Contracts
- Construct a LGA / PHL basket
Pricing: How Much is it Worth to PU?

- **Actuarial / Historical Approach**
  - Burn Analysis
  - Temperature Modeling & Monte Carlo VaR Computations
  - Not Enough Reliable Load Data

- **Expected (Exponential) Utility Maximization** (A. Danilova)
  - Use Gas & Power Contracts
  - Hedging in Incomplete Models
  - Indifference Pricing
  - Very Difficult Numerics (whether PDE’s or Monte Carlo)
Enron Global Markets LLC
P.O. BOX 1188
HOUSTON, TX 77251-1188

DATE 11/13/2001  NO. 1000001124

PAY
TO THE ORDER OF

Eleven Thousand and NO/100 Dollars
RENE CARMONA PRINCETON UNIVERSITY OR FE DEPT PRINCETON NJ 08544

CITIBANK DELAWARE, A SUBSIDIARY OF CITICORP
ONE PENN'S WAY, NEW CASTLE, DE 19720

$11,000.00

NOT VALID AFTER 1 YEAR
FIRST CLASS MAIL

Att. Rene Carmona
Princeton University
ORFE Dept
Princeton NJ 08544
Weather Derivatives

OTC & Exchange traded (29 cities on CME)

- Still Extremely Illiquid Markets (except for front month)
- Misconception: Weather Derivative = Insurance Contract
  - No secondary market
  - Mark-to-Market (or Model) does not change
- Not Until Meteorology kicks in (10-15 days before maturity)
  - Mark-to-Market (or Model) changes every day
  - Contracts change hands
  - That’s when major losses occur and money is made
- This hot period is not considered in academic studies
  - Need for updates: new information coming in (temperatures, forecasts, ....)
  - Filtering is (again) the solution
Weather Derivatives

OTC & Exchange traded (29 cities on CME)

- Still Extremely Illiquid Markets (except for front month)

- Misconception: Weather Derivative = Insurance Contract
  - No secondary market
  - Mark-to-Market (or Model) does not change

- Not Until Meteorology kicks in (10-15 days before maturity)
  - Mark-to-Market (or Model) changes every day
  - Contracts change hands
  - That’s when major losses occur and money is made

- This *hot period* is not considered in academic studies
  - Need for updates: new information coming in (temperatures, forecasts, ....)
  - Filtering is (again) the solution
Weather Derivatives

OTC & Exchange traded (29 cities on CME)

- Still Extremely *Illiquid* Markets (except for *front month*)
- **Misconception:** Weather Derivative = Insurance Contract
  - No secondary market
  - Mark-to-Market (or Model) does not change
- Not Until Meteorology kicks in (10-15 days before maturity)
  - Mark-to-Market (or Model) changes every day
  - Contracts change hands
  - That’s when major losses occur and money is made
- This *hot period* is not considered in academic studies
  - Need for *updates:* new information coming in (temperatures, forecasts, ....)
  - Filtering is (again) the solution
Weather Derivatives

OTC & Exchange traded (29 cities on CME)
- Still Extremely **Illiquid** Markets (except for **front month**)
- **Misconception**: Weather Derivative = Insurance Contract
  - No secondary market
  - Mark-to-Market (or Model) does not change
- Not Until Meteorology **kicks in** (10-15 days before maturity)
  - Mark-to-Market (or Model) **changes** every day
  - Contracts change hands
  - That’s when major losses occur and money is made
- This **hot period** is not considered in academic studies
  - Need for updates: new information coming in (temperatures, forecasts, ....)
  - Filtering is (again) the solution
Weather Derivatives

OTC & Exchange traded (29 cities on CME)

- Still Extremely Illiquid Markets (except for front month)
- Misconception: Weather Derivative = Insurance Contract
  - No secondary market
  - Mark-to-Market (or Model) does not change
- Not Until Meteorology kicks in (10-15 days before maturity)
  - Mark-to-Market (or Model) changes every day
  - Contracts change hands
  - That’s when major losses occur and money is made
- This hot period is not considered in academic studies
  - Need for updates: new information coming in (temperatures, forecasts, ....)
  - Filtering is (again) the solution
Daily Average Temperature at La Guardia.
Prediction on 6/1/2001 of daily temperature over the next four months.
The Future of the Weather Markets

- **Social function** of the weather market
  - Existence of a Market of Professionals (for weather risk transfer)

- **Under attack** from
  - (Re-)Insurance industry
  - Utilities (trying to pass weather risk to end-customer)
    - EDF program in France
    - Weather Normalization Agreements in US

- **Cross Commodity Products**
  - Gas & Power contracts with weather triggers/contingencies
  - New (major) players: **Hedge Funds** provide liquidity

- **World Bank**
  - Use weather derivatives instead of insurance contracts
The Future of the Weather Markets

- **Social function** of the weather market
  - Existence of a Market of Professionals (for weather risk transfer)

- **Under attack** from
  - (Re-)Insurance industry
  - Utilities (trying to pass weather risk to end-customer)
    - EDF program in France
    - Weather Normalization Agreements in US

- **Cross Commodity Products**
  - Gas & Power contracts with weather triggers/contingencies
  - New (major) players: **Hedge Funds** provide liquidity

- **World Bank**
  - Use weather derivatives instead of insurance contracts
The Future of the Weather Markets

- **Social function** of the weather market
  - Existence of a Market of Professionals (for weather risk transfer)

- **Under attack** from
  - (Re-)Insurance industry
  - Utilities (trying to pass weather risk to end-customer)
    - EDF program in France
    - Weather Normalization Agreements in US

- **Cross Commodity Products**
  - Gas & Power contracts with *weather triggers/contingencies*
  - New (major) players: **Hedge Funds** provide liquidity

- **World Bank**
  - Use weather derivatives instead of insurance contracts
The Future of the Weather Markets

- **Social function** of the weather market
  - Existence of a Market of Professionals (for weather risk transfer)

- **Under attack** from
  - (Re-)Insurance industry
  - Utilities (trying to pass weather risk to end-customer)
    - EDF program in France
    - Weather Normalization Agreements in US

- **Cross Commodity Products**
  - Gas & Power contracts with *weather triggers/contingencies*
  - New (major) players: **Hedge Funds** provide liquidity

- **World Bank**
  - Use weather derivatives instead of insurance contracts
The Future of the Weather Markets

- **Social function** of the weather market
  - Existence of a Market of Professionals (for weather risk transfer)

- **Under attack** from
  - (Re-)Insurance industry
  - Utilities (trying to pass weather risk to end-customer)
    - EDF program in France
    - Weather Normalization Agreements in US

- **Cross Commodity Products**
  - Gas & Power contracts with *weather triggers/contingencies*
  - New (major) players: **Hedge Funds** provide liquidity

- **World Bank**
  - Use weather derivatives instead of insurance contracts
Temperature Options: Actuarial/Statistical Approach
Temperature Options: Diffusion Models (Danilova)
Precipitation Options: Markov Models (Diko)

- Problem: Pricing in an Incomplete Market
- Solution: Indifference Pricing à la Davis

\[ d\theta_t = p(t, \theta)dt + q(t, \theta)dW^{(\theta)}_t + r(t, \theta)dQ^{(\theta)}_t \]
\[ dS_t = S_t[\mu(t, \theta)dt + \sigma(t, \theta)dW^{(S)}_t] \]

- \( \theta_t \) non-tradable
- \( S_t \) tradable
Example: **Exponential Utility Function**

\[
\tilde{p}_t = \frac{\mathbb{E}\{\tilde{\phi}(Y_T) e^{-\int_t^T V(s, Y_s) ds}\}}{\mathbb{E}\{e^{-\int_t^T V(s, Y_s) ds}\}}
\]

where

- \( \tilde{\phi} = e^{-\gamma(1-\rho^2)t} \)
  - where \( f(\theta_T) \) is the pay-off function of the European call on the temperature

- \( \tilde{p}_t = e^{-\gamma(1-\rho^2)p_t} \)
  - where \( p_t \) is price of the option at time \( t \)

- \( Y_t \) is the diffusion:

  \[
dY_t = [g(t, Y_t) - \frac{\mu(t, Y_t) - r}{\sigma(t, Y_t)} h(t, Y_t)] dt + h(t, Y_t) d\tilde{W}_t
  \]

  starting from \( Y_0 = y \)

- \( V \) is the time dependent potential function:

  \[
  V(t, y) = -\frac{1 - \rho^2}{2} \frac{(\mu(t, y) - r)^2}{\sigma(t, y)^2}
  \]
The Weather Market Today

- Insurance companies: Swiss Re, XL, Munich Re, Ren Re
- Financial Houses: Goldman Sachs, Deutsche Bank, Merrill Lynch, ABN AMRO
- Hedge funds: D. E. Shaw, Tudor, Susquehanna, Centaurus, Wolverine

**Trading**

- OTC
- Exchange: CME (Chicago Mercantile Exchange) 29 cites globally traded, monthly / seasonal contracts
- Strong end-user demand within the energy sector Northeast and Midwest LDCs most prevalent in US
Only a subset of locations are traded on a daily basis
Exchange settlement prices depart from OTC market prices (viewed by traders)
Denoting by $\mu$ the mean of the swaps delivering in a given season, by $\Sigma$ their covariance matrix:

$$\inf_{\mu, \Gamma_\mu = \pi} (\mu - \mu_{sim}^t \Sigma^{-1} (\mu - \mu_{sim}))$$

where $\Gamma$ defines the set of observable trades and $\pi$ is the vector of market prices.