Energy Markets III: Weather Derivates

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- **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

Other Statistical Issues: Modelling Demand

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 = β * weather + α
    - Not true all the time
    - Time dependent β 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**

Power Plant Risk Management

- **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**

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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

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Review: **Classical Optimal Stopping Problem: American Option**

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

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

Mathematical Solution

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

Standard, Well Understood

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New Mathematical Challenges

In its simplest form the problem of **Swing/Recall** option pricing is an

Optimal Multiple Stopping Problem

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

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

- **Refraction** period θ

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

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 $\rightarrow$ Multiple exercise, Vesting $\rightarrow$ Refraction, $\cdots$
  - Fleet Purchase (airplanes, cars, $\cdots$)
- **Challenges**
  - Valuation
  - Optimal exercise policies
  - Hedging

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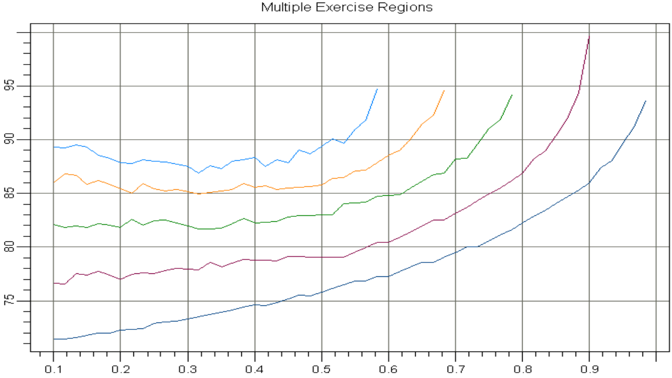

Exercise regions for $N = 5$ rights and finite maturity computed by Malliavin-Monte-Carlo.

First Faculty Meeting of New PU President

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

Risk Management Solution

- Never Again such a Short Fall !!!
- Student (Greg Larkin) Thesis
- **Hedging Volume Risk**
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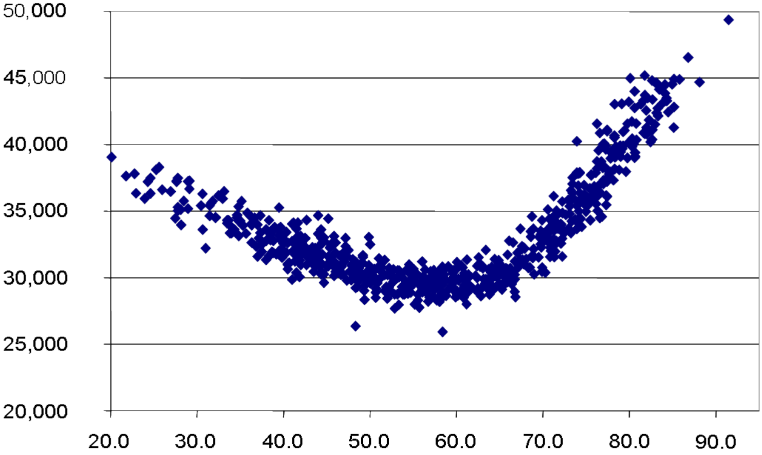

Average Daily Load against Average Daily Temperature (PJM data).

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 *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)


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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

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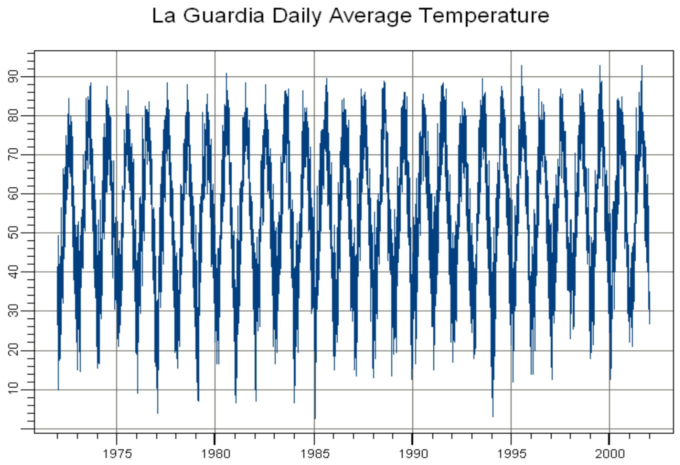
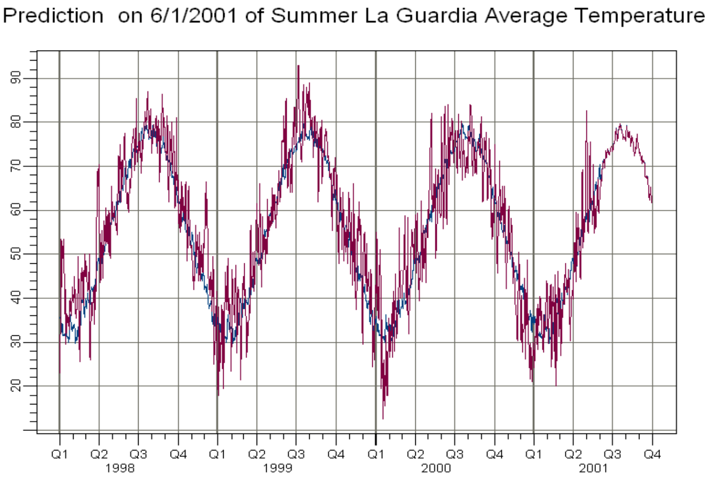


Daily Average Temperature at La Guardia.



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

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Incomplete Market Model & Indifference Pricing

- 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

$$
\begin{aligned}
d\theta_t &= p(t,\theta)dt + q(t,\theta)dW_t^{(\theta)} + r(t,\theta)dQ_t^{(\theta)} \\
dS_t &= S_t[\mu(t,\theta)dt + \sigma(t,\theta)dW_t^{(S)}]
\end{aligned}
$$

  - θ_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

- $\tilde{\phi} = e^{-\gamma(1-\rho^2)f}$
  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

Marking-to-Market

- Only a subset of locations are traded on a daily basis
- Exchange settlement prices depart from OTC market prices (viewed by traders)
- Denoting by μ the mean of the swaps delivering in a given season, by Σ their covariance matrix:

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

where Γ defines the set of observable trades and π is the vector of market prices.