Electricity Markets Risk Management and Optimization

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Outline

- Comparison to currency, fixed income and direct investment real estate
- Assets and Liabilities
- Asset Representation
- Distributional Properties
- Case Study – Renewables in a medium sized country
Similarities

Direct investment real estate

- Power Generation Facilities
  - Highly illiquid
  - Long term investments
  - Geographically fixed
  - May provide income in a foreign currency
  - Electricity price as the Numéraire
  - Income amount is uncertain and related to specific factors

Currency/Fixed income

- Power Purchase Agreement (PPA)
  - Currency swap
  - The buyer of the PPA receives electricity while paying currency
  - Currency paid in exchange for electricity can be constant or inflation linked
Differences

Direct investment real estate

- Power Generation Facilities
  - Highly seasonal cash flows
  - Payment depends directly on weather outcomes
    - In the US weather related outcomes are often hedgeable
    - In other smaller countries these hedges may not exist or may be expensive
      - Risk must be managed through diverse portfolio allocation

Currency/Fixed Income

- Different return distribution properties
- Electricity cannot be stored at any significant volume leading to price spikes
- Electricity in different geographical places is different
  - More like physical commodities which must be moved (known transmission costs)
  - Cannot be moved between many locations
- Price taker paradigm is invalid in markets with few participants
  - High degrees of market impact
Assets and Liabilities Considered

• Power generation facilities
  – Focusing today on two types of renewable power plants
    ▪ Photovoltaic
    ▪ Hydroelectric
• Power Production Agreements (PPA)
• Spot Energy
• American real options (Dixit and Pindyck (1994))
  – Representing the option to expand existing infrastructure
Asset Representation

- Portfolios of elements within an extended Everything Everywhere model
  - A single asset may be represented as a portfolio of separate assets within the linear model
- New factors
  - Sun
  - Wind
  - Rainfall
- Existing factors
  - Oil
  - Global Bonds
  - Treasury Curve factors 1, 2 and 3
- Options are represented as a leveraged portfolio with tail-matching distributional behavior
Robust Optimization

- Similar to real estate, assets in this case are
  - Illiquid
  - Indivisible
- Optimization input parameters are estimated with error
  - Distance between portfolios measured in Euclidean sense under mean vs standard deviation two dimensional space
  - Calculate different efficient frontiers for feasible values of parameters
    - Discretization over risk aversion parameter (RAP)
  - Drop the farthest 10% of portfolios for the sake of robustness
    - Distance relative to traditional efficient frontier
  - Find the portfolio which falls within the density center of each region by RAP adding further robustness
- Bey, Burgess and Cook (1990), DiBartolomeo (1993)
Distributional Properties

• Hourly Electricity Returns Stylized (Eydeland and Wolyniec (2003))
  – Positive Sample Skewness
  – Sample Leptokurtosis (excess kurtosis, fat tails) (Cont (2001))
  – Mean reversion
  – Jumps in some markets
• Power Generation
  – Weather dependent
  – Highly seasonal
  – Irregular income streams
• Negative correlation between electricity generation and electricity price in small markets
• Data
  – Solar: one year of hourly generation data
  – Hydroelectric: 27 years of monthly data from 1972-1999
Solar Power Generation

Hourly Power Output

Output

Month

Jan Apr Jul Oct Jan
Solar Power Generation

One year power output by hour

Output

Month
Solar Power Generation

Total Hour Output

Output

Hour

Month

12
11
10
9
8
7
6
5
4
3
2
1

5000
10000
15000
0

Solar Power Generation

Fitted Daily Generation

Output (MwH daily) vs Time in years
Hydroelectric Power Generation
Hydroelectric Power Generation

Autocorrelation Function Hydro 1
Diversification

Hydroelectric VS Solar

Output (Gwh)

Month

Data Type
- Mean Hydro
- Total Solar
Summary

- Comparison to other markets
- Assets and their representation
- Distributional properties of renewable generation facilities
- Results
  - Allocation between assets to achieve diversification over technologies (photovoltaic, wind and hydroelectric)
  - Optimal hedging of spot electricity exposure via PPAs
References - Questions

Value of the power generation facility

\[ V_t = \sum_{i} E_t^*[P_{T_i}] E_t^*[E_{T_i}] B(t, T_i) + \sum_{i} \text{Cov}_t^*[P_{T_i}, E_{T_i}] B(t, T_i) \]

- Definitions
  - \( B(t, T) \) Price of the zero coupon bond at time \( t \) paying 1 currency unit at time \( T \)
  - \( P_{T_i} \) Aggregate production of electricity from time \( T_{i-1} \) to time \( T_i \)
  - \( E_t \) Electricity price at time \( t \)

- Assumes independence of zero coupon bond price with energy prices and production
- The value of the generating facility if electricity price were uncorrelated with production plus the cost of covariance of production and electricity price
- The extent to which the covariance is negative determines the drag on the value of the power production facility
- Sensitivities to treasury curve factors are determined via central finite difference