NORTHFIELD | modeling financial markets worldwide

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

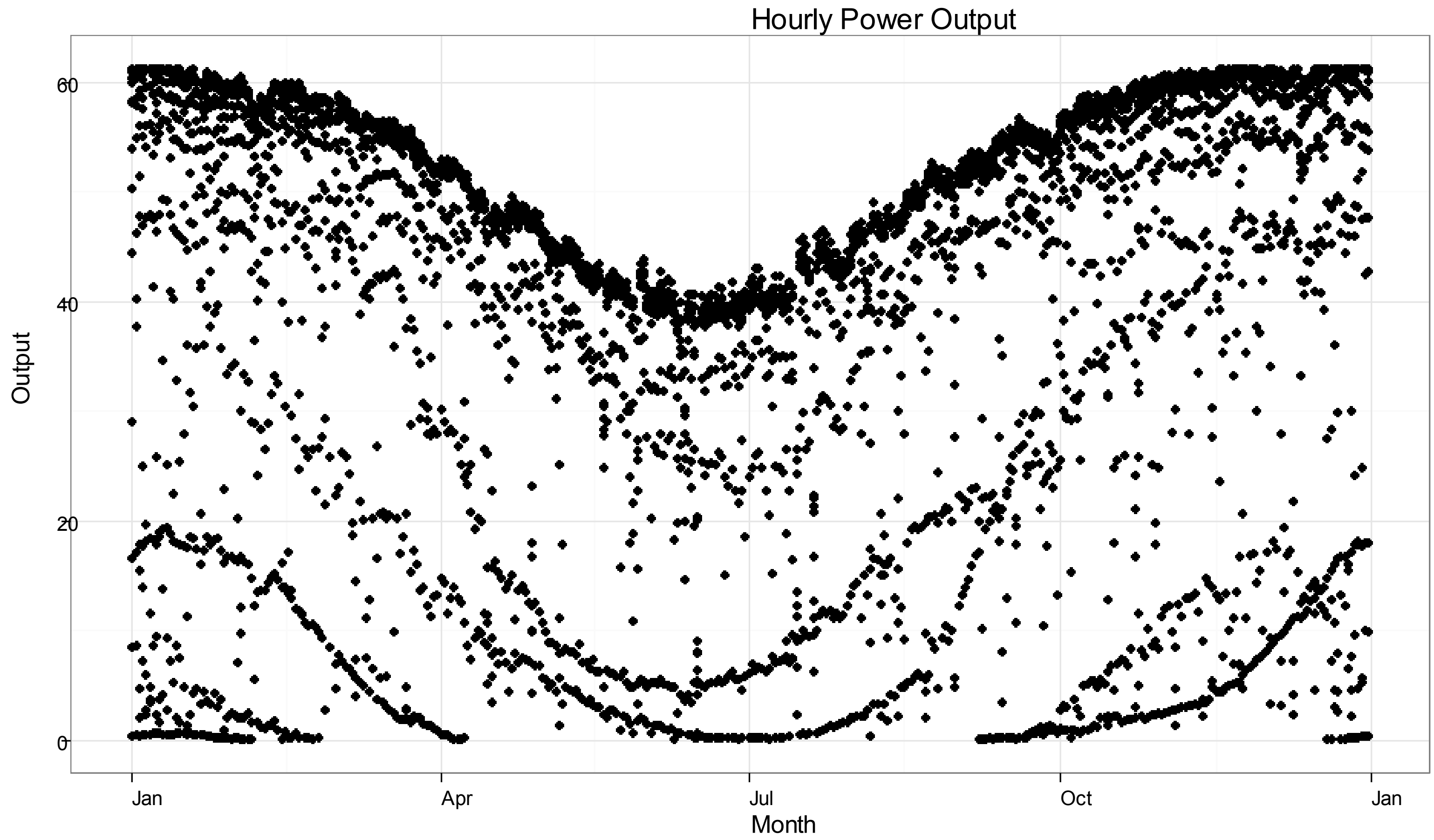
Robust Optimization

- 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)

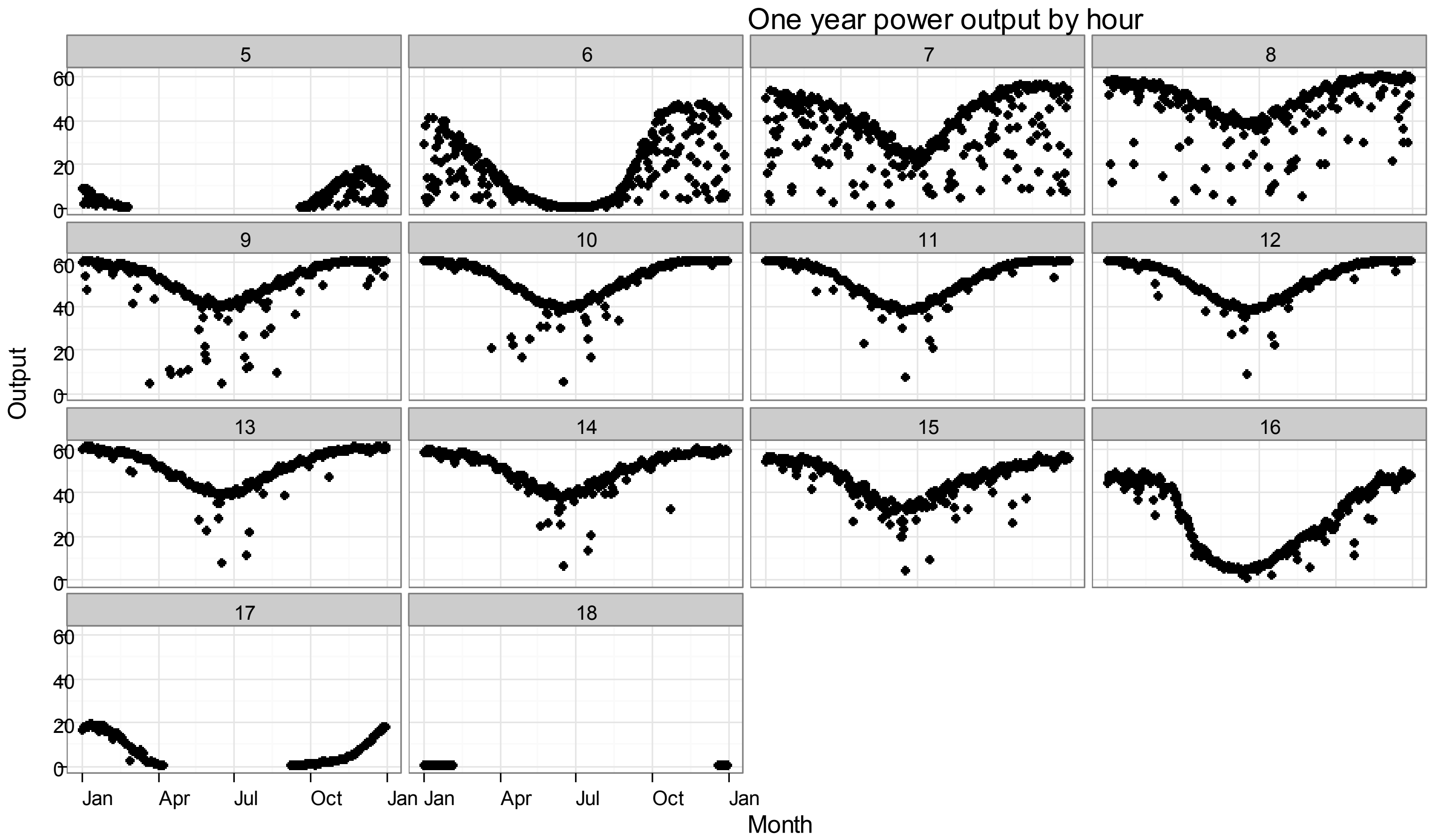
Distributional Properties

- 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

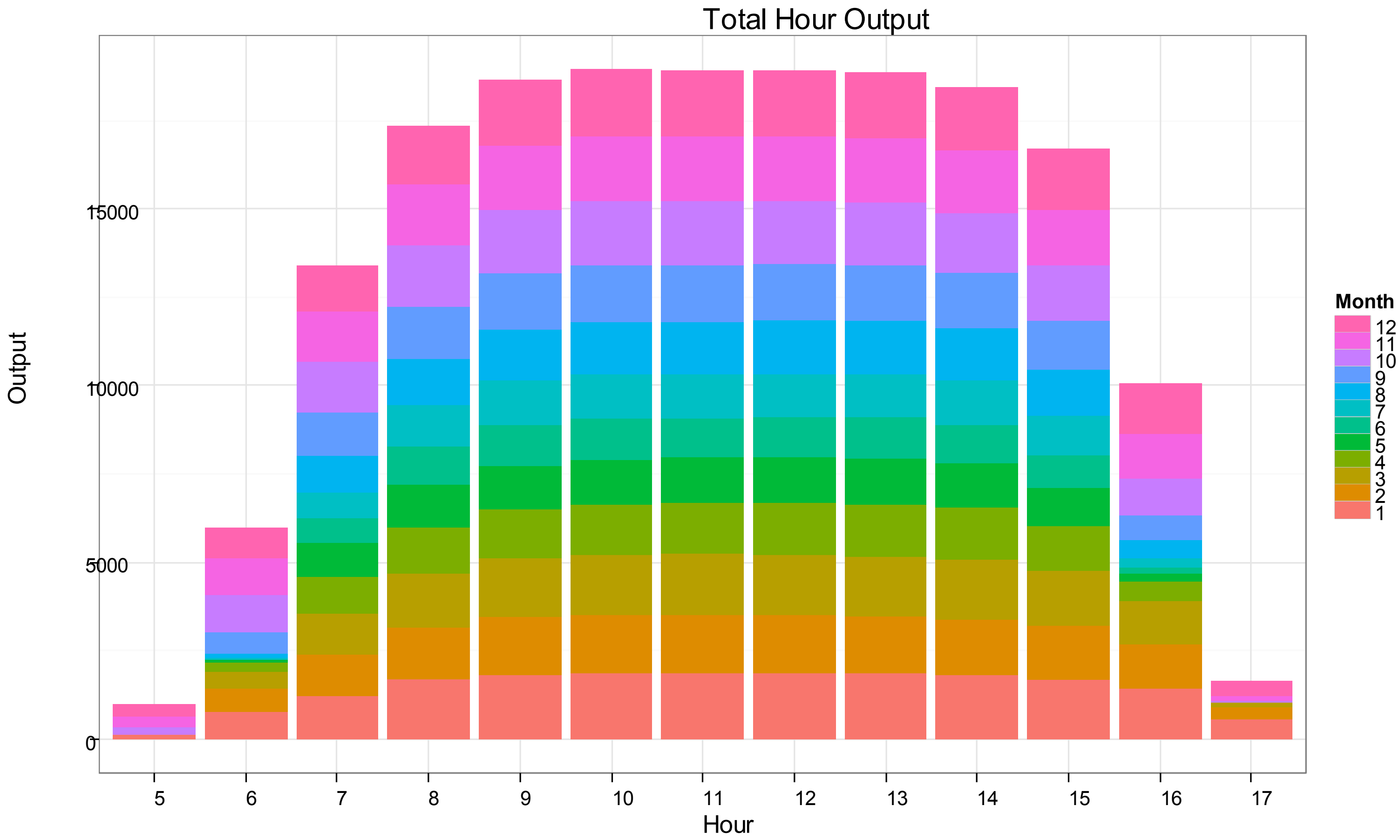
Solar Power Generation



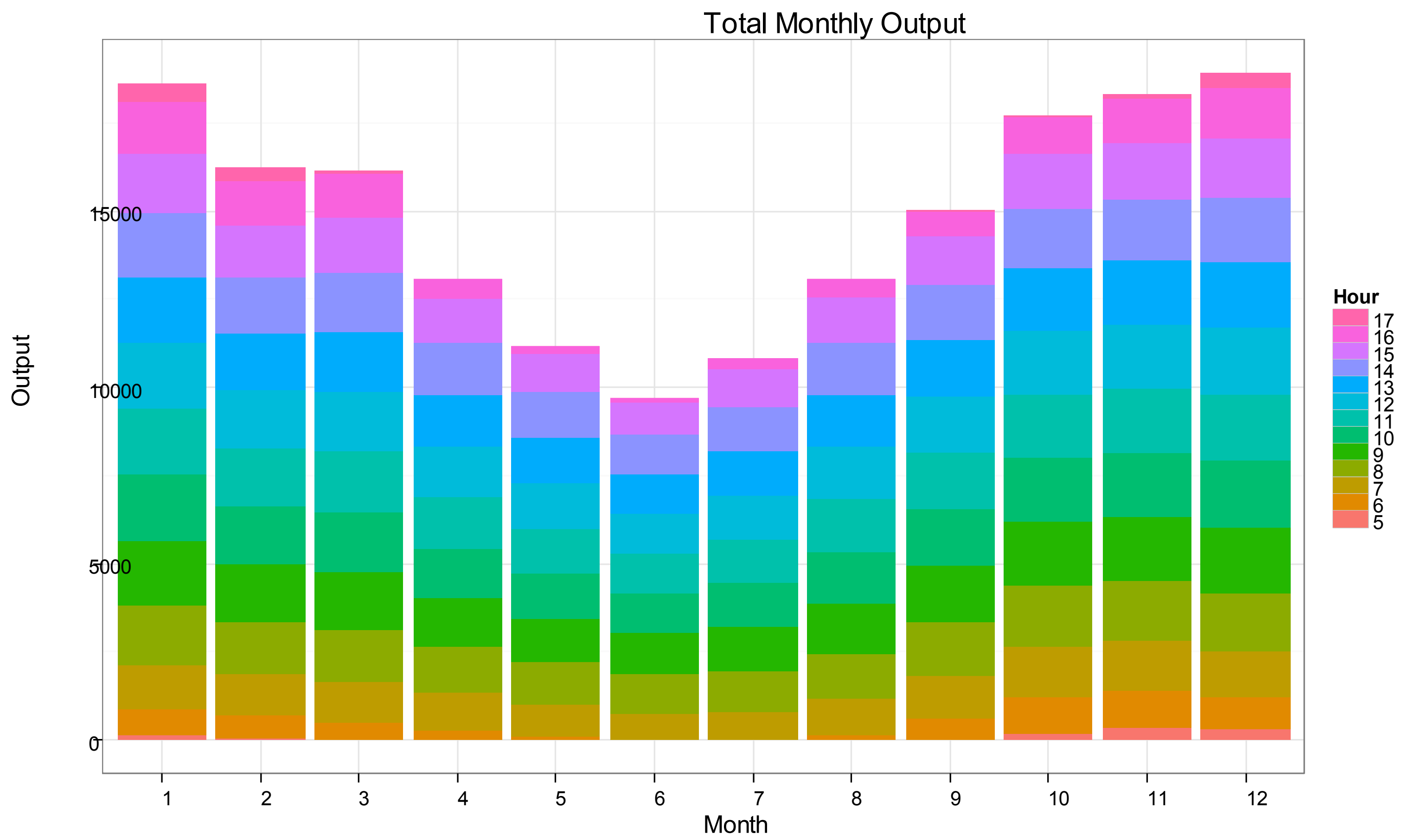
Solar Power Generation



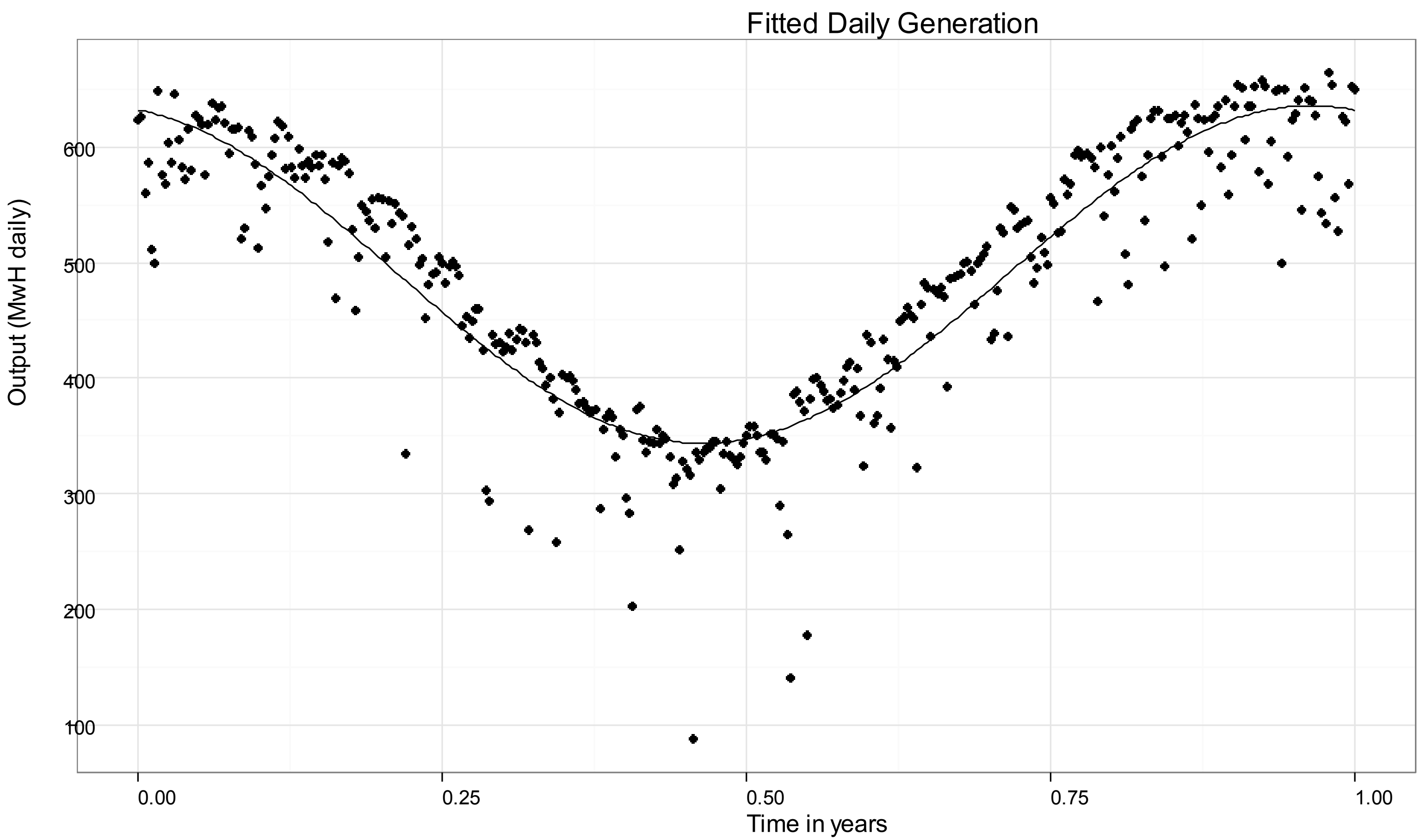
Solar Power Generation



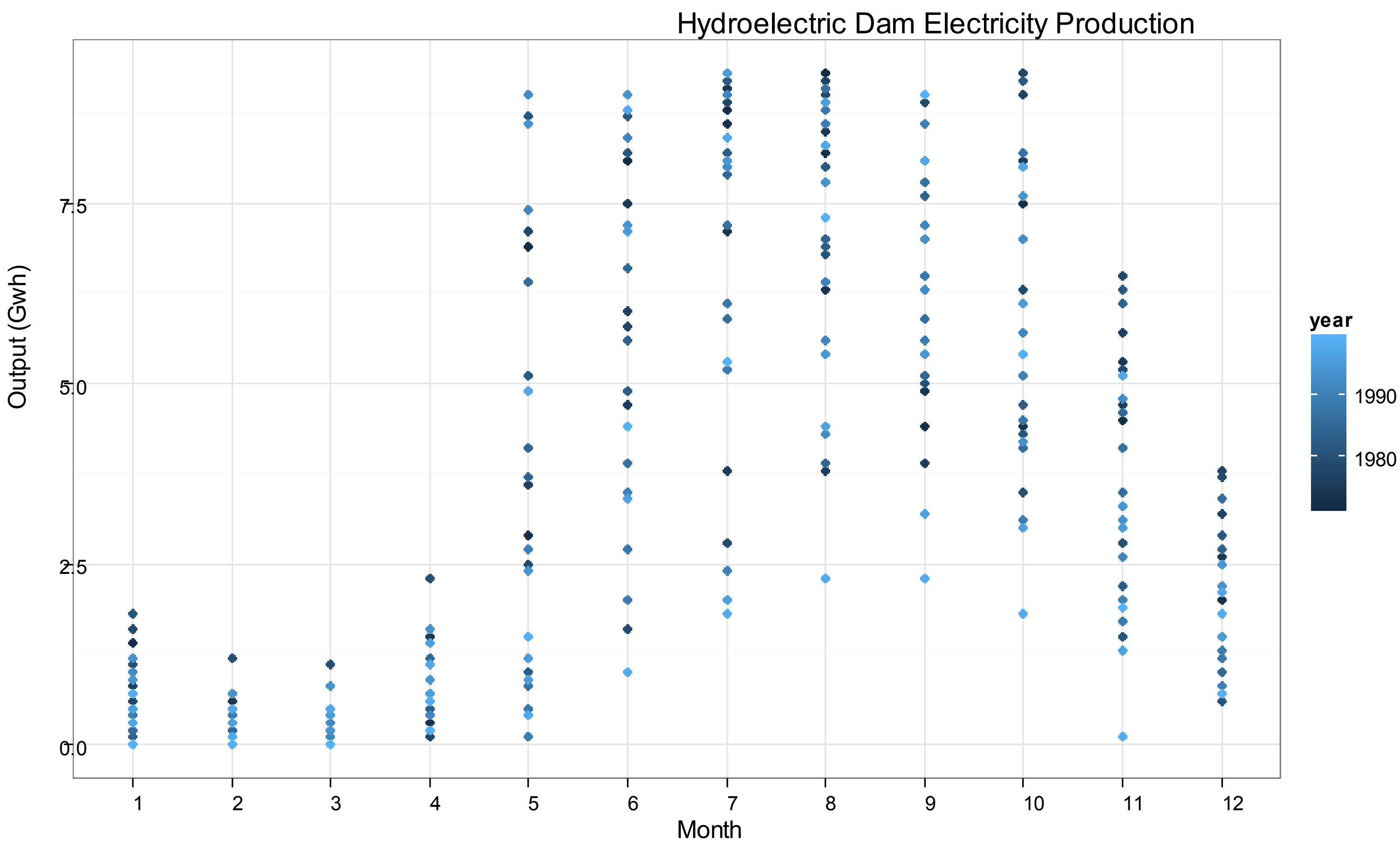
Solar Power Generation



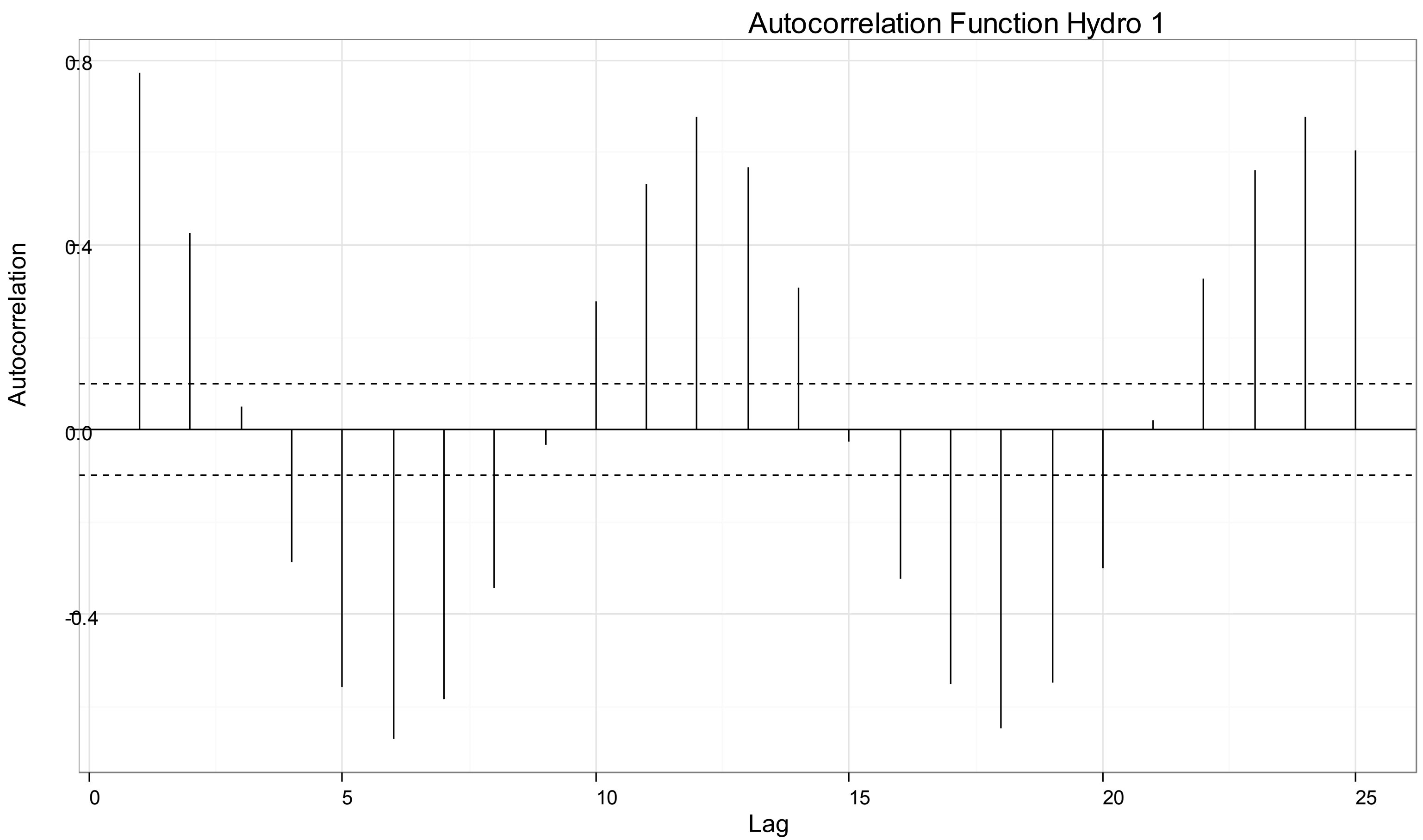
Solar Power Generation



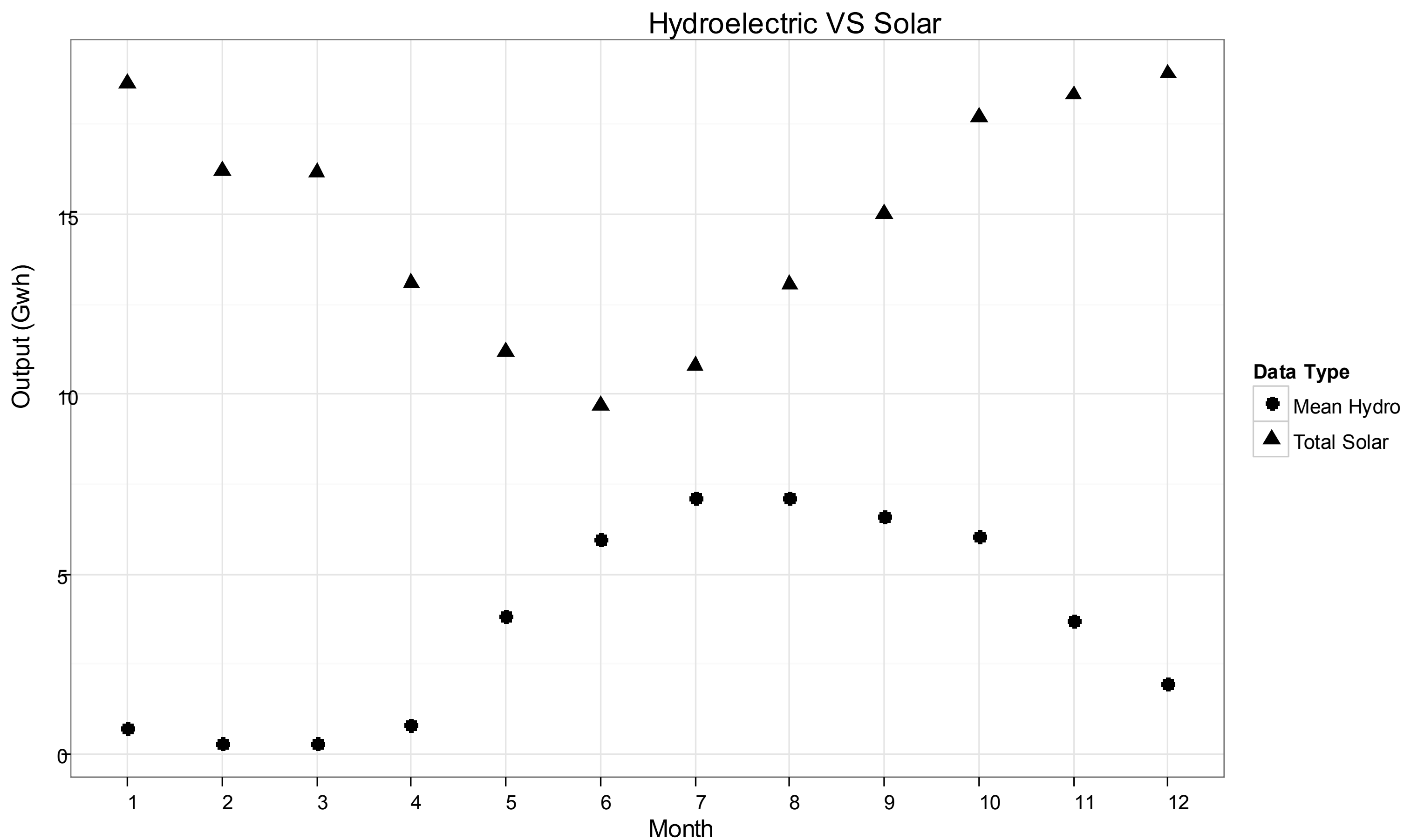
Hydroelectric Power Generation



Hydroelectric Power Generation



Diversification



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

- Dixit, Avinash and Robert Pindyck, *Investment Under Uncertainty*, Princeton University Press, 1993
- Eydeland, Alexander and Krzysztof Wolyniec, *Energy and Power Risk Management: New Developments in Modeling, Pricing and Hedging*, Wiley, 2002
- Gold, Richard B., *Why the Efficient Frontier for Real Estate Is "Fuzzy"*, Journal of Real Estate Portfolio Management, Volume 1, Number 1, 1995
- Bey, Burgess and Cook, *Measurement of Estimation Risk in Markowitz Portfolios*, University of Tulsa, unpublished, 1990
- DiBartolomeo, Dan, *Portfolio Optimization: The Robust Solution*, Northfield Research http://northinfo.com/Documents/45.pdf, 1993
- Park, R.E., *Estimation with Heteroscedastic Error Terms, Econometrica*, 34, 888., 1966
- Rama Cont, *Empirical properties of asset returns: stylized facts and statistical issues*, Quantitative Finance, Vol. 1, No. 223-236., 2001

Value of the power generation facility

- $V_t = \sum_{T_i} \mathrm{E}_t^\star[P_{T_i}]\mathrm{E}_t^\star[E_{T_i}]B(t,T_i) + \sum_{T_i} \mathrm{Cov}_t^\star[P_{T_i}, E_{T_i}]B(t,T_i)$
  - 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