Mid-Term Stochastic Modeling of Energy Markets and its Applications

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THE EnergyAuthority

Power Utility Industry

- The Energy Authority serves public utilities nationwide for trading and analytics.
- Mid-term (1 month – 5 years) portfolio management.
- Stochastic simulation models for energy and gas market.

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Types of Energy Market Models

Short-Term (ST)

15 min ~ A few weeks

- System Operations
- Scheduling
- RT/DA Trading

Operational must- haves

Mid-Term

1 months ~ several years

- Budgeting
- Trading/Hedging

Optional

Long-Term (LT)

A few decades

- LT planning
- Investment and divestitures
- Policy development

Regulatory must- haves

Traditional Approach to Mid-Term Modeling

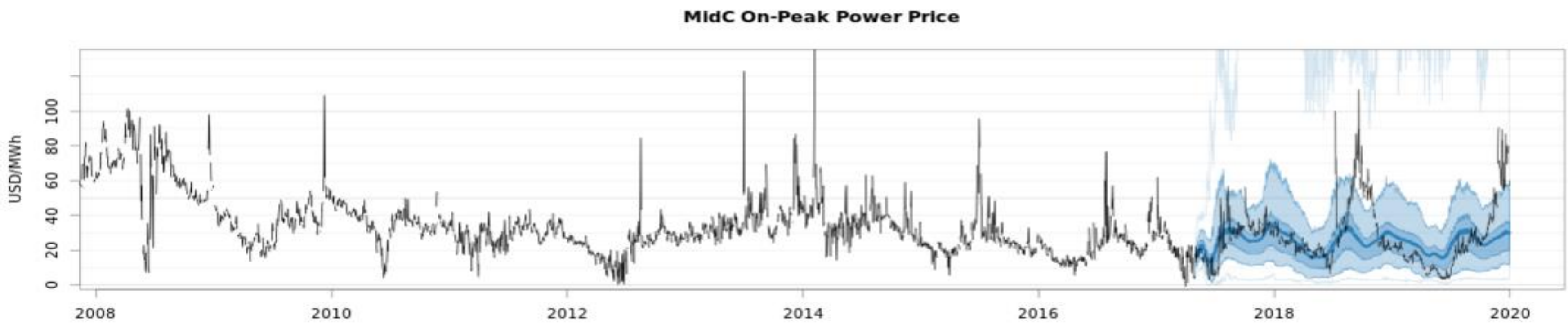
- Use commercially available **cost-production models**
  - Many utilities already have ST and TL models. Utilize those for mid-term modeling by simply adjusting the simulation time.
  - Some cost-production models
    - Focus only on particular resource dispatches. In these models, power prices are often generated by a simple random variable generator.
      - ☒ Too simplistic and cannot capture the time series behaviors.
    - Are system optimization models that generate power prices as a result of system-wide grid simulation.
      - ☒ Can be too sensitive to small changes and takes too long to run. For active trading purposes, it's too slow.
- Solution

☑ **Statistical simulation**

  - Right after wholesale energy market restructuring, cost-production model made sense. But we have gotten enough historical data for building robust statistical model now.

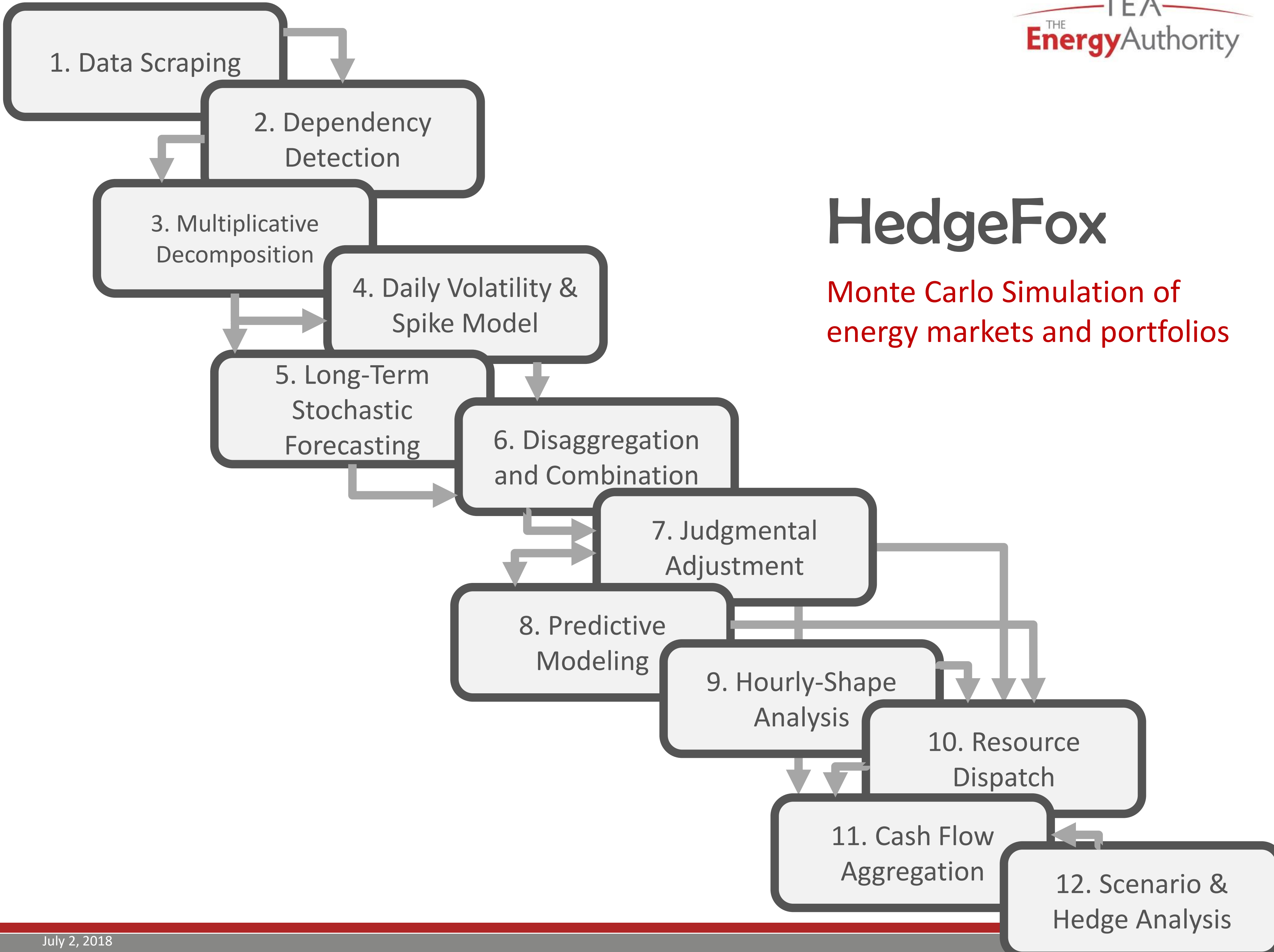
Power Price TS Characteristics

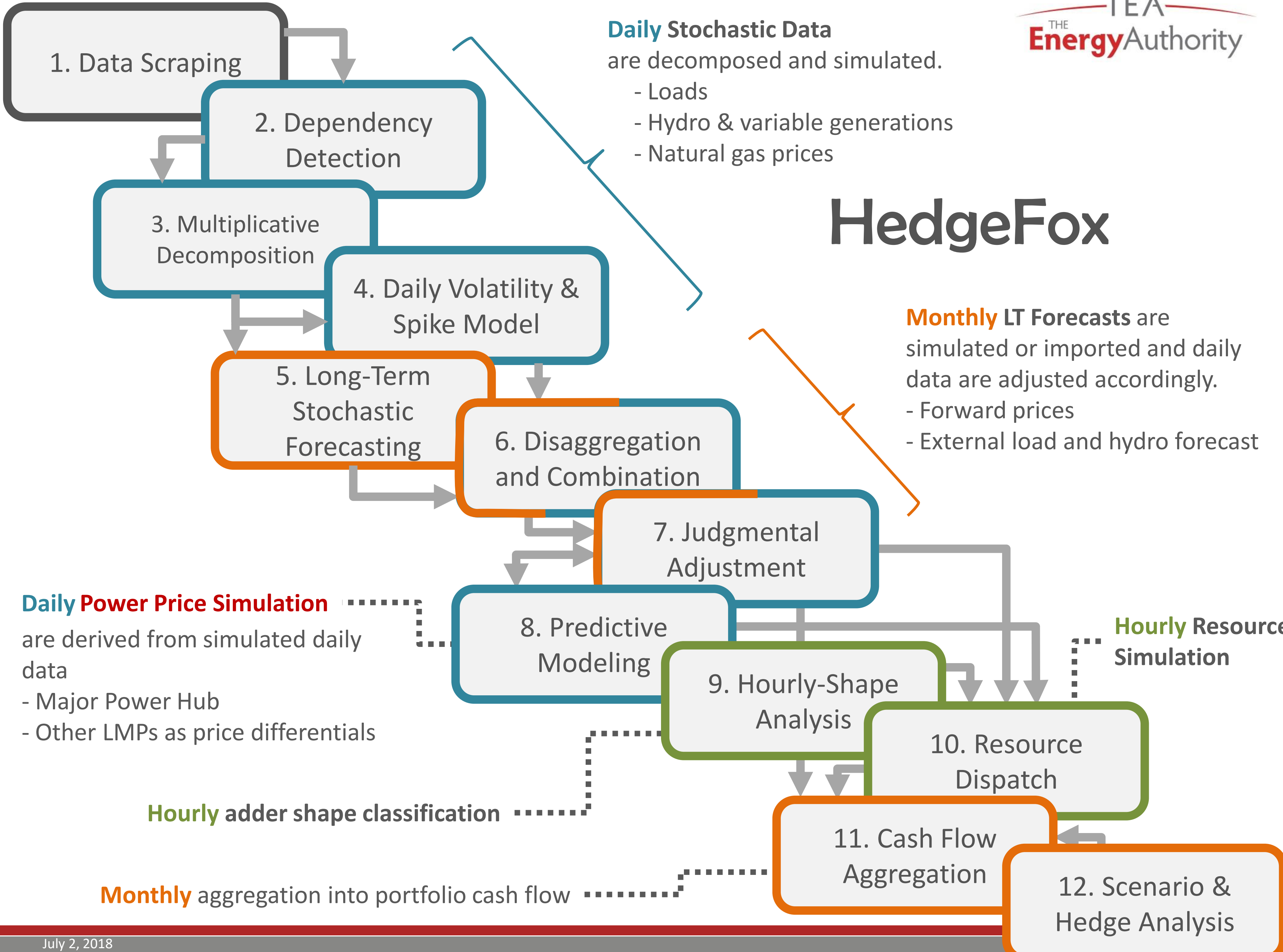
- Autocorrelation
- Seasonal and weekly shapes
- Volatility & Heteroscedasticity
  - Seasonal and weekly variability
- Multivariate cross-correlation and non-linear dependency
  - NG, load, regional hydro and other variable generation
- Non-normal distributions
  - fat tails
  - Extreme peaks and drops
- Negative prices
- Consistency with market expectations
- Consistency among different time granularities.



HedgeFox

Monte Carlo Simulation of energy markets and portfolios




1. Data Scraping
2. Dependency Detection
3. Multiplicative Decomposition
4. Daily Volatility & Spike Model
5. Long-Term Stochastic Forecasting
6. Disaggregation and Combination
7. Judgmental Adjustment
8. Predictive Modeling
9. Hourly-Shape Analysis
10. Resource Dispatch
11. Cash Flow Aggregation
12. Scenario & Hedge Analysis
Daily Stochastic Data
are decomposed and simulated.
- Loads
- Hydro & variable generations
- Natural gas prices
HedgeFox
Monthly LT Forecasts are simulated or imported and daily data are adjusted accordingly.
- Forward prices
- External load and hydro forecast
Daily Power Price Simulation
are derived from simulated daily data
- Major Power Hub
- Other LMPs as price differentials
Hourly Resource Simulation
Hourly adder shape classification
Monthly aggregation into portfolio cash flow

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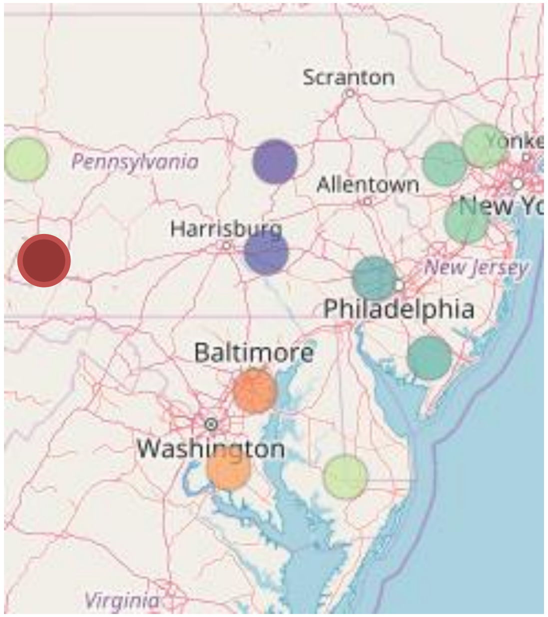
Power Price Simulation

- Simulate multiple prices as price differentials to one major hub price.
- Feature space
  - Autoregressive terms
  - Month and Day-of-Week
  - Already simulated fundamentals such as solar, wind & hydro generation, gas prices and multiple loads
  - Power price series at a major hub
  - All other LMP price differential simulated prior to the particular LMP
- Feature space may not include all price drivers.



Common Approach for Stochastic Modeling

- $Price = f(\ldots) + Error(\ldots)$
  Where f is some sort of regression model

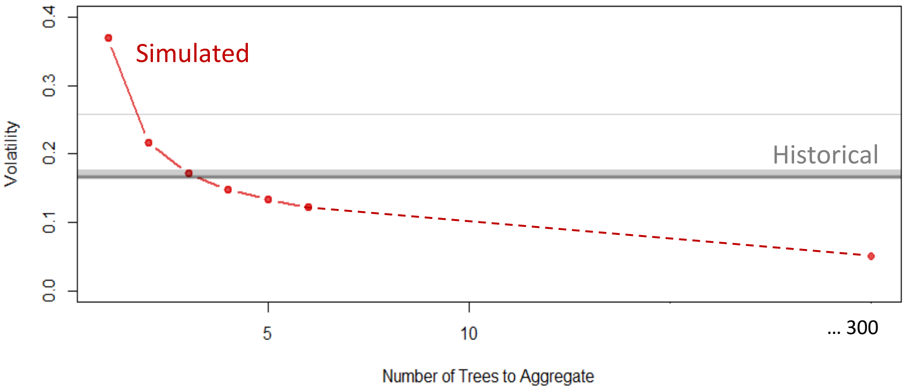
- Requirements for the residuals
  - ☒ Normal distribution
  - ☒ f's features need to include enough information
  - ☒ Need careful examinations of error terms for each variables.
- If requirements are met, the correct level of volatility should be captured automatically, but otherwise, volatility may not match.

- We need something robust for the error terms.

Bunched Random Forest

- Random Forest
  - Aggregation of a few hundred trees moderate values too much → **Low volatility**
  - a single tree encompasses too little predictability → **High volatility**
- Bunched RF in MC
  - Aggregating a selected number of trees for each Monte Carlo iteration
  - Achieve plausible volatility in each MC series, while maintaining the same predictability as RF in the whole MC simulation.

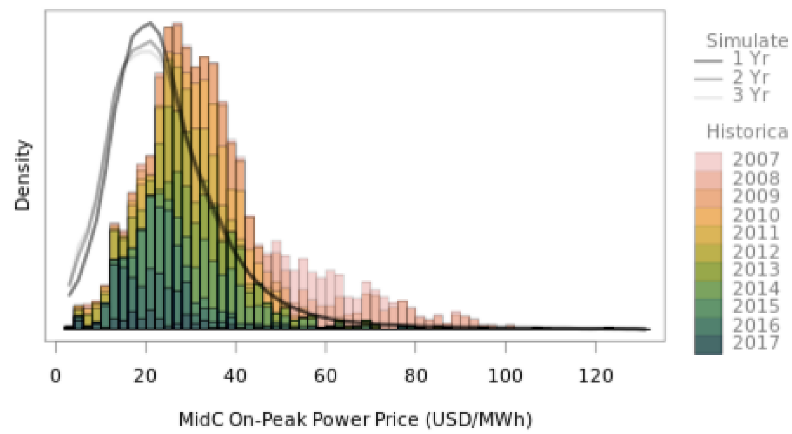
- Implementation
  - randomForest::predict.randomForest() includes individual tree outputs.
  - After figuring out the bunching number based on historical volatility, sample and aggregate suitable number of individual tree outputs.



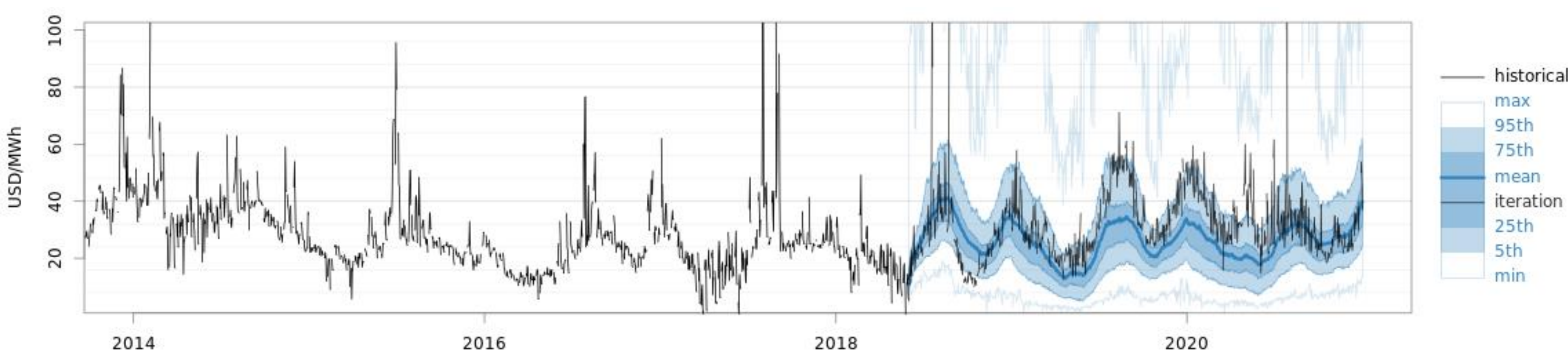
Results

✓ Price distribution (overall and at monthly level).

Price Distribution

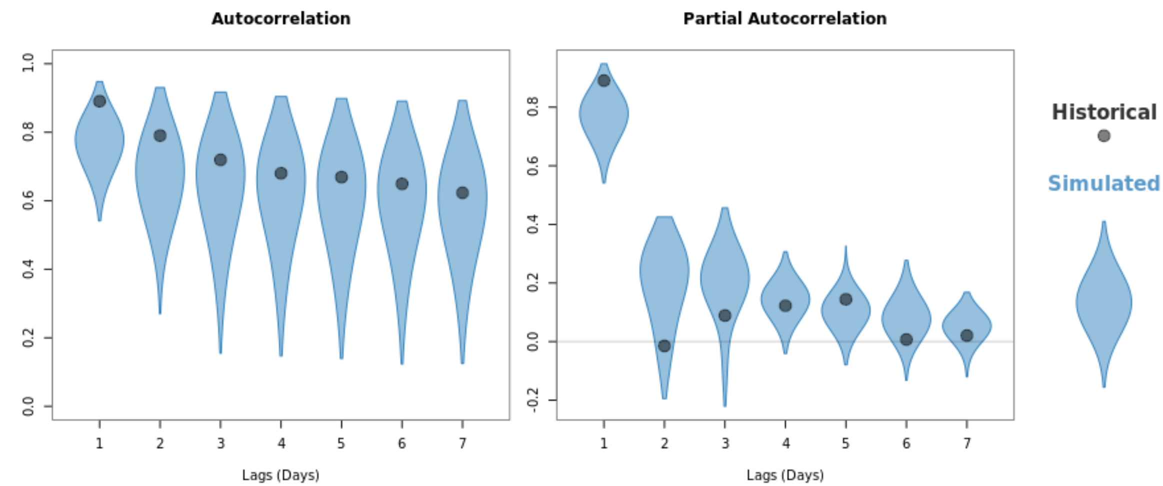


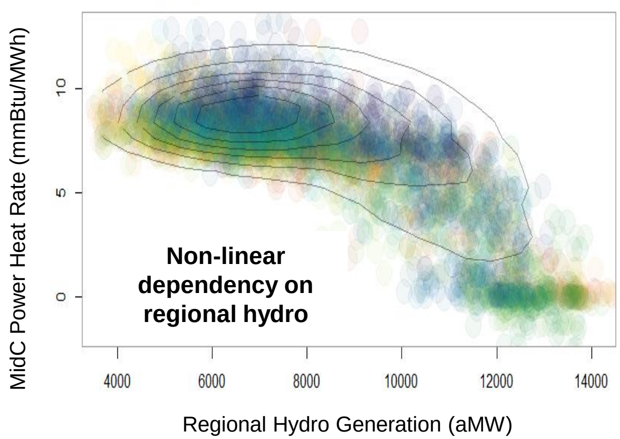
Mid-C Power Price (Historical + Simulated)

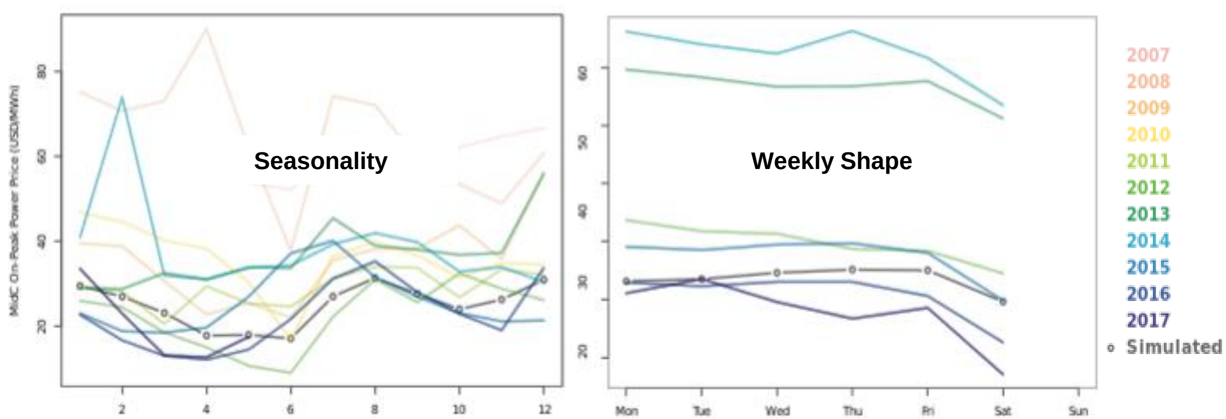


Results

- ✓ Autocorrelation
- ✓ Seasonal Shapes
- ✓ Weekly shapes
- ✓ Non-linear dependencies





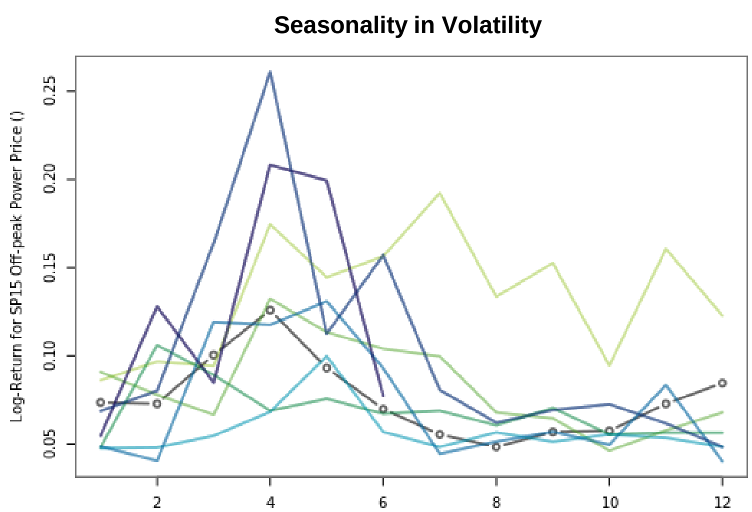


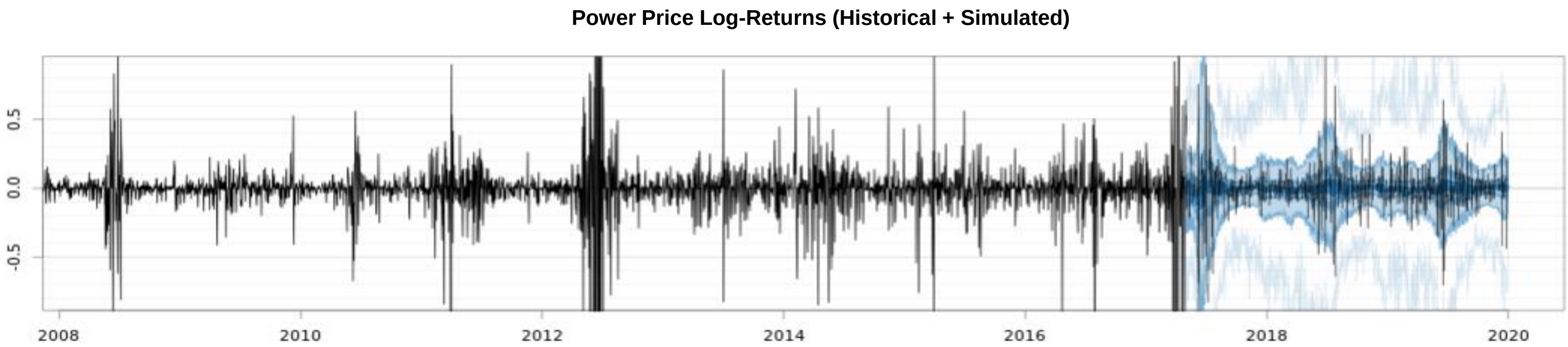
Results

✓Volatility

✓Heteroscedasticity

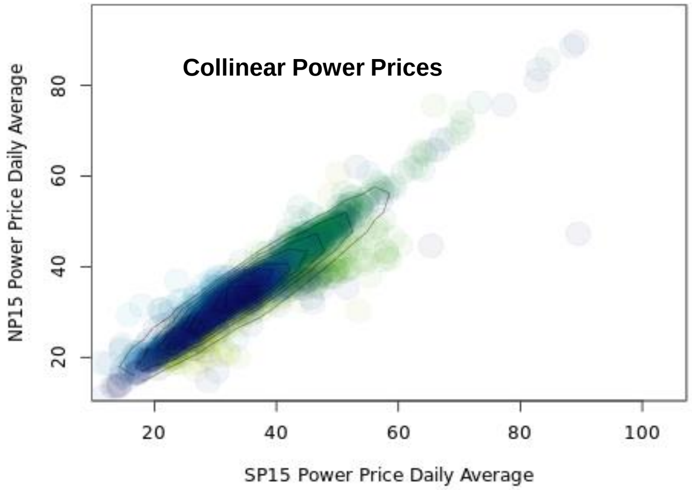
✓Seasonality

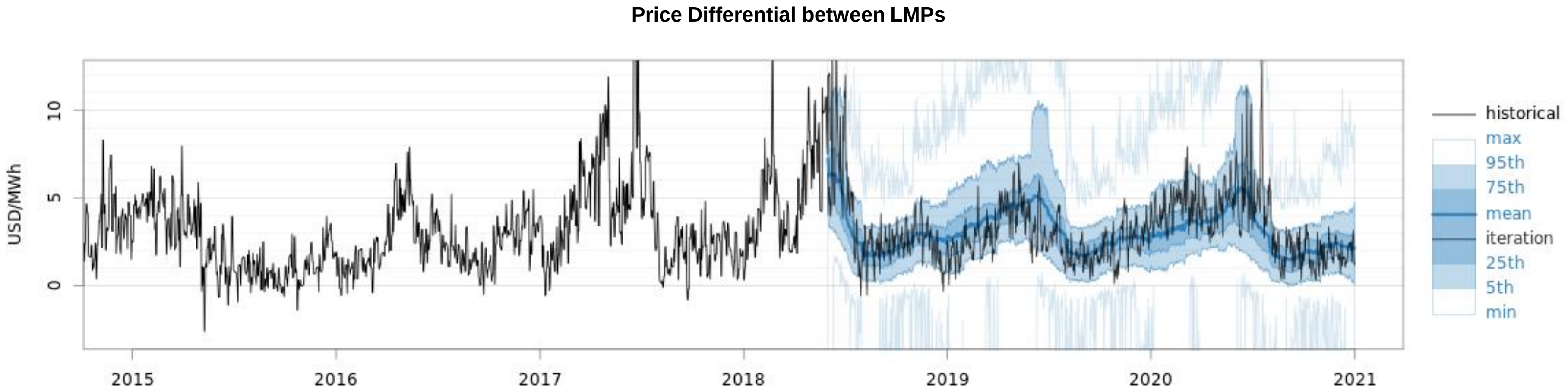




Results

✓ Multivariate cross-correlations





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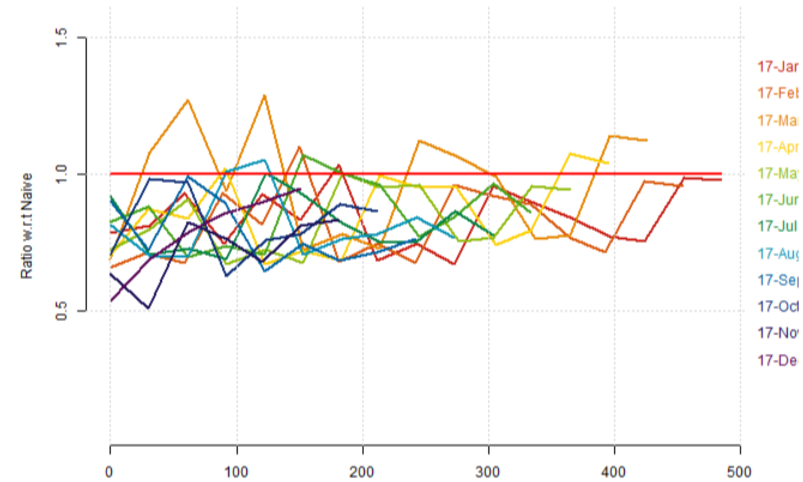
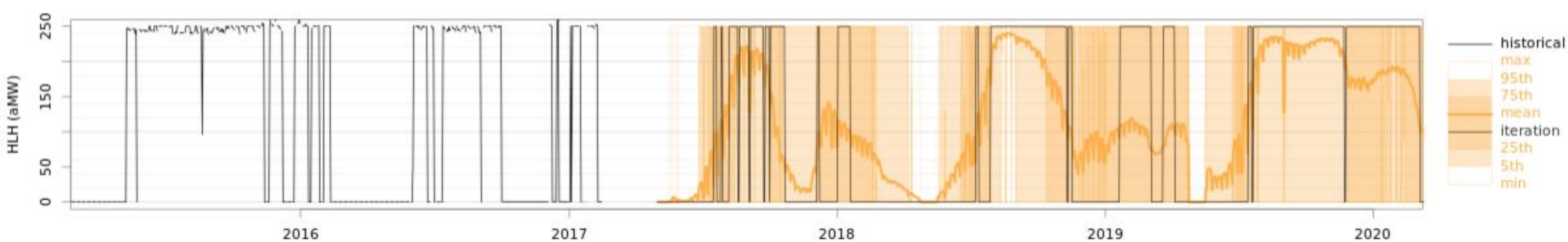
Scoring Methods

In order to make sure that all needed behaviors are captured multiple scoring methods are used.

1. Volatility
   - ✓ Check is simulated volatility matches with historical.
2. CRPS against naïve model
   - ✓ Calculate ratio between CRPS of simulated and naïve models
3. Pinball Loss Score on Resource dispatch simulation outputs
   - ✓ Resource dispatch model transforms power price behavior to cash flow. This combines and checks many of the power price characteristics.



Natural Gas Resource Dispatch (Historical + Simulated)



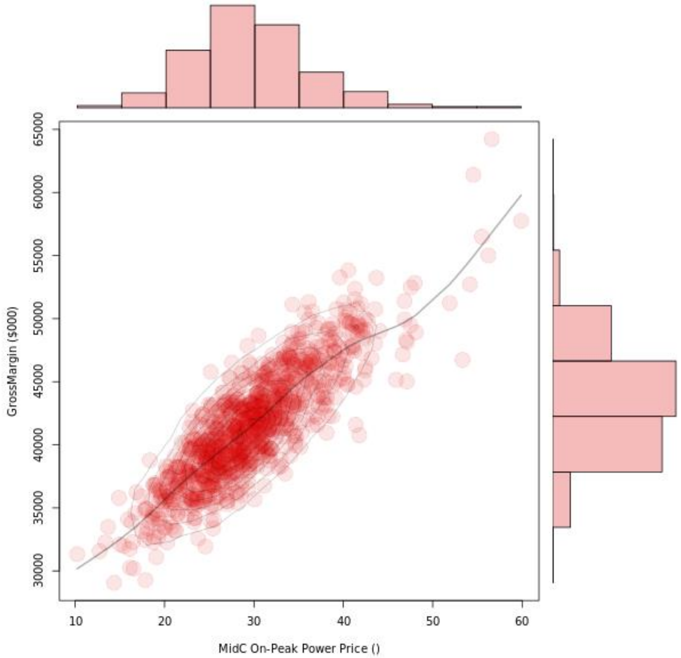
Summary of BRF

- Benefits
  - No concern about residual behaviors.
  - Robust in feature space (many collinear variables or too little drivers)
  - Volatility is automatically adjusted in the process.
  - Heteroscedasticity is captured.
  - Variable importance can be insightful in learning the drivers of particular price nodes.

- Limitations
  - Difficult to tune bunching numbers, particularly when a large number of prices are derived sequentially.

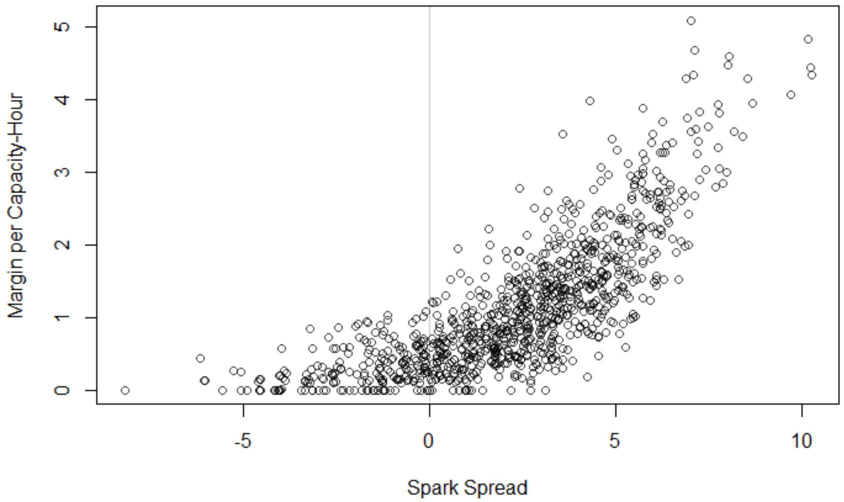
Delta Hedging

- **Delta** is the change in portfolio value with respect to market prices.
- **Delta neutral** is a portfolio strategy where portfolio value remains unchanged when small changes occur in the market.
- Some of the risk averting utilities like to manage portfolios actively, and requires a swift market & portfolio model.



Delta Hedging of a Thermal Unit

- Natural gas resources can be treated as a 'real option' with respect to spark spread.
  - Spark Spread = Power Price – (HeatRate x Gas Price + VOM)



- Through dynamic delta-hedging, realization of extrinsic value is possible.
  - Have a market and resource model be always up-to-date.
  - Watch spark spread and corresponding delta on daily basis.
  - When market moves, trade heat rate. Unwinding positions should lock in positive cash flow.

My slide can be found at https://github.com/einaooka

Thank you!

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The Energy Authority is looking for an intern.