THE ANALYSIS OF ELECTRICITY DEMAND AND PRICE PATTERNS OF THE UNITED STATES ELECTRICITY SECTOR

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Why extreme value theory?

- Allows us to model extreme and rare events of independent, identically distributed random variables.

- Unlike classical statistics that focus analysis on average behavior of stochastic processes, EVT focuses on the tail of distributions and helps to analyze and predict the trend of rare events.

Source: (Friederichs, 2007)
Motivation

- Deregulation and new energy policies have changed how electricity is being traded
- Dynamic electricity demand, limited storability
- As a result, we see spikes and sudden changes in the electricity load and prices

WHY ANALYZING EXTREME VALUES IS IMPORTANT?

- Prevent blackouts
- Launch DR programs
- Investment decisions
- Risk Management
- Load Forecasting
Utilizes **hourly observations** available through Federal Energy Regulatory Commission (FERC) to analyze periods of peak demands and high electricity prices with the help of extreme value theory (EVT).

Estimate generalized extreme value (**GEV**) distribution parameters by accounting for the time dependencies, seasonality, and near-time clustering.

Discuss few electricity market issues where we may be able to apply the techniques of time-series modelling and EVT.

Data availability and use of same model specification across market regions and electricity entities are few caveats.
Time series plot of hourly load and lambda

PJM Hourly load (GW): 2000 - 2012

NYISO Hourly lambda ($/MWh): 2000 - 2012
Electricity sector exhibits strong correlation across different time horizons

Since EVT relies on i.i.d., there is a need to account for the time dependencies and seasonalities in the electricity markets before employing EVT.


We use AR(1), AR(2), AR(24), and GARCH(1,1)

\[ x_t = \beta_0 + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \beta_3 x_{t-24} + \varepsilon_t \]
\[ \sigma_t^2 = \gamma_0 + \gamma_1 \varepsilon_{t-1}^2 + \gamma_2 \sigma_{t-1}^2 \]
Extreme Value Theory: Peak-Over-Threshold method

- Takes observations that are larger than certain threshold level despite of the blocks that they belong to, thus uses data more efficiently than the block-maximum method.

- The selected observations are asymptotically distributed following a Generalized Pareto Distribution:
  \[ H(y|X_i > u) = 1 - \left(1 + \frac{y}{\sigma_u} \right)^{-\frac{1}{\xi}} \]
  such that \( y > 0 \) and \( \left(1 + \frac{y}{\sigma_u} \right) > 0 \) where \( \sigma_u = \sigma + \frac{\xi(u - \mu)}{\xi} \)

- Shape parameter \( \xi \) determines the tail behavior of the family of distributions
Federal Power Act requires each balancing authority submit hourly lambda values and mandates electricity providers (> 200 MW) report hourly load information.

Data available through FERC 714 forms

The source and formats of the data are not consistent. Available in three different places within FERC website

Final dataset
- 9.72 million hourly loads – 119 Unique Electricity providers;
- 3.34 million hourly lambdas – 48 Unique Balancing Authorities
Distribution of hourly observations – PJM region: 2000-2012

PJM Hourly load (GW)

PJM Hourly Lambda ($/MWh)
Average Annual Load Shape Parameters

By Year

By Year and Geographic Region

![Graphs showing load shape parameters by year and by geographic region.](image)

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Average Annual Lambda Shape Parameters

By Year

By Year and Geographic Region
Why Estimate Tail Quantiles?

- Assess the risks that electricity sector is exposed to and investigate “worst-case” scenarios. This is analogous to estimating “value-at-risk” is finance and investment sectors.
- Estimate certain “return value” at a given period utilizing GEV parameters in load forecasting for assessing uncertainty.
# Quantile Estimates – Hourly Load

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- The table provides tail quantiles estimation at 99 percentile level.
- Unconditional tail quantiles of hourly load have better estimates than AR/GARCH model at 99 percentiles.
- The AR/GARCH quantiles underestimate the value-at-risk at 99-percentile level, except in the cases of Duke Energy, New York Control Area, PJM, and Tennessee Valley Authority.
- Unconditional quantiles are comparable to the actual data, AR/GARCH model overestimates the tail quantiles.
- Using hourly change in lambda values instead of actual lambdas in estimating tail quantiles may be a better idea.

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<th>Respondent ID</th>
<th>Reporting Agency Name</th>
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We show that the GEV Shape parameters vary over time and location... and why is this relevant?

- Compare load extreme values versus capacity and assess how that varies over time and location, organization type. This may give us an idea on efficiency among different entities.

- Similarly, we could compare lambda extreme values vs. wholesale electricity prices over time and location and organization type. This would suggest the value of excess capacity strategy to cope with load variation.

- We may be also able to use these lambda GEV parameters to improve day ahead forecasts of wholesale prices.
Other Possible Extensions

- **Other possible extensions**
  - If wholesale electricity prices are admin set and also the transmission congestion cost. Can we argue it is of specific interest to consider **lambda as it reflects marginal cost**?
  - Taking this further... we may be able to use hourly lambda’s, GEV parameters along with wholesale electricity prices to estimate **congestion cost**? At the same time, we also need to consider that the congestion cost might reflect variation in need for additional capacity?
Conclusion

- Present a simple way to estimate extreme value occurrence with the help of extreme value theory.
- Provide a comprehensive analysis of extreme tail characteristics of different market regions’ hourly electricity load and prices.
- Our results indicate that distributions of hourly load and lambda values are fat tailed. Hourly lambda values have more extreme values generating fatter tails than hourly electricity load.
- The EVT and time-series technique can be applied to variety of electricity market issues. The issue of forecasting vs. capacity, and forecasting using lambda might be thematically interesting.
References

- Fuller, 1914
- Griffith. 1920.
- Stata Crop
Extreme Value Distributions

![Graph of Extreme Value Distributions](image)
Earliest work on EVT was done by Fuller (1914), Griffith (1920), Fisher and Tippet (1928), Gnedenko (1943), Gumbel (1958)

Few of the recent books such as Kotz and Nadarajah (2000) and Coles (2001) provide excellent theory and review of extreme value distributions.

Most of the EVT literature on electricity markets focus on modeling and estimating the changes in wholesale electricity prices.

Bystrom (2005) and Chan and Gray (2006) use generalized extreme value distribution to AR-GARCH filtered price change series to investigate the tails of the electricity price change distribution.

Spees (2008) treats peak load as extreme value to predict the total capacity necessary to serve forecasted load in the NE-ISO region.
Relationship between Average and Peak Demand

![Graph showing the relationship between average and peak demand over time.](image)

- **% diff between peak and average loads**
- **100% (Peak - Average)/Average**

Year:
- 1995
- 2000
- 2005
- 2010
- 2015

Lines:
- **PJM**
- **NEISO**
- **NYISO**

Note: Graph illustrates the fluctuation in percentage difference between peak and average loads over different regions.
Hourly observation by year

Observations above 95 percentile

Extreme Value Model

Detailed descriptive statistics

GPD Parameters

Unconditional quantile estimates

Conditional mean, variance

Conditional quantile estimates

\[ \alpha_p = u + \frac{\sigma}{\xi} \left( \left( \frac{n}{n_u} \right)^{-\xi} - 1 \right) \]

\[ \alpha_{t,p} = \hat{x}_t + \sigma_t \alpha_p \]
Forty one out of 54 electricity entities have hourly load observations that are skewed right, indicating that hourly load observations are skewed right — the right tail is long relative to the left tail.

Fifty four unique electricity providers have kurtosis value greater than 3.

Average hourly electricity demand is 3.53 GW ranging from 0.13 GW of City of Burbank, CA to 32.01 GW of PJM Interconnection.

Descriptive Stats – Hourly Loads
### Descriptive Stats – Hourly Lambdas

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- 16 unique balancing authorities.
- Average lambda values range from $16.69/MWh to $46.06/MWh.
- Sample kurtosis values of all 17 respondents are greater than 3 – varying from 4.03 to 179.28.
- Positive sample skewness values of all respondents.