Forecasting Natural Gas Demand using Hierarchical Frameworks

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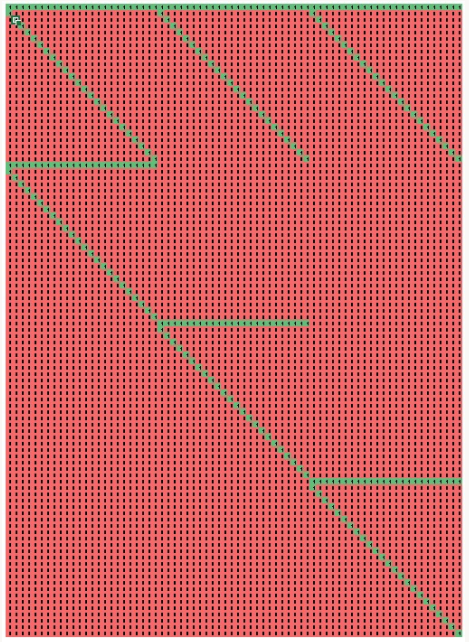
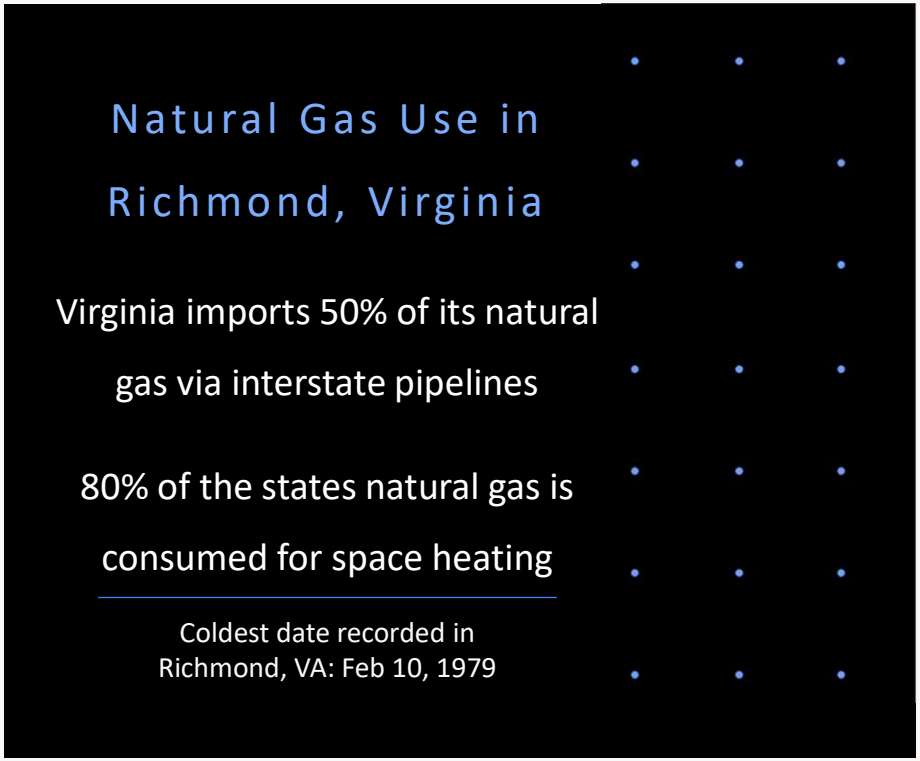
Agenda

- Natural gas consumption, demand, and forecasting
  - Coherent forecasts, aligned decision making
  - Natural gas consumption data organized hierarchically
- Hierarchical forecasting framework
  - Cross-sectional
  - Temporal
  - Cross-temporal
- Cross-temporal reconciliation of natural gas demand forecasts
- Results
  - Next steps



Natural gas consumption, demand, and forecasting

- Natural gas is a fossil fuel energy source extracted for sale and consumption
  - Residential, commercial, and industrial uses
- Gas consumption data can be hierarchically organized to improve demand forecasting
- Typical forecast horizons
  - Operational: hourly, daily
  - Strategic: monthly, yearly, multi-year



http://www.virginiaplaces.org/transportation/gaspipeline.html
https://www.rva.gov/public-utilities/natural-gas-utility

Coherent forecasts, aligned decision making

- Gas distribution utilities rely on demand forecasts to support decision making at different levels and functions

Level	Horizon	Scope	Forecasts	Methods	Information
Operational	Short	Local	Way too many	Statistical	Univariate/Hard
Tactical	Medium	Regional	↕	↕	↕
Strategic	Long	Global	Few, expensive	Experts	Multivariate/Soft

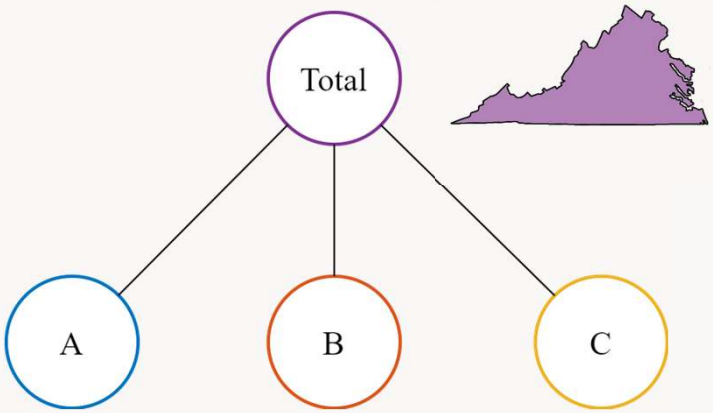
[1]

- Forecasts supporting decision-making should be aligned
  - Coherent forecasts allow aligned decisions
  - Ex: Daily -> Monthly
- Challenge: forecasts at individual levels rarely align and provide conflicting intra-level results

1 - Kourentzes, N., Athanasopoulos, G.: Cross-temporal coherent forecasts for Aus- tralian tourism. Annals of Tourism Research 75, 393–409 (2019)
35. Liaw, A., Wiener, M.: Classification and regression by randomforest. R News 2(3), 18–22 (2002), https://CRAN.R-project.org/doc/Rnews/

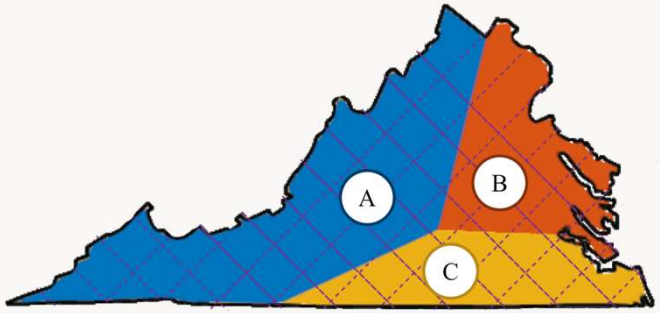
Natural gas consumption data organized hierarchically

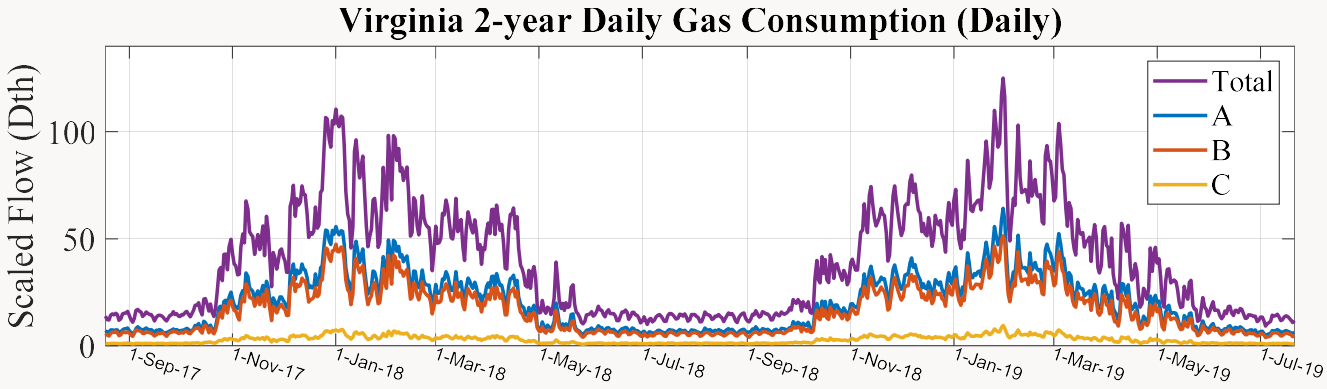
- Two approaches to organizing data hierarchically
  1. **Cross-sectional**
  2. Temporal



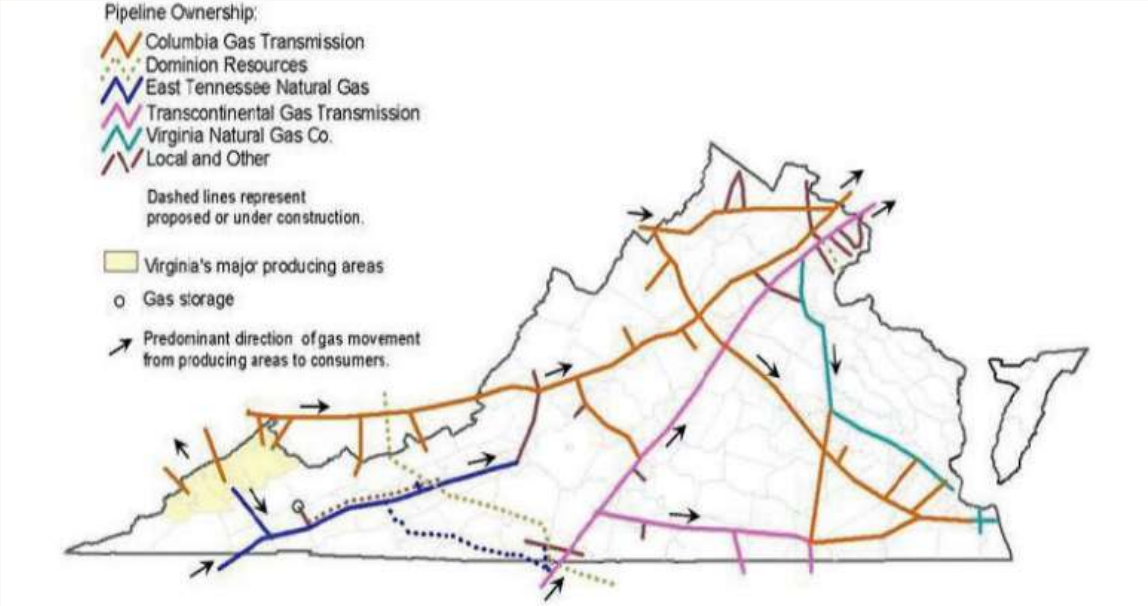
- Example: gas consumption data organized geographically
  - Locked to the time of analysis

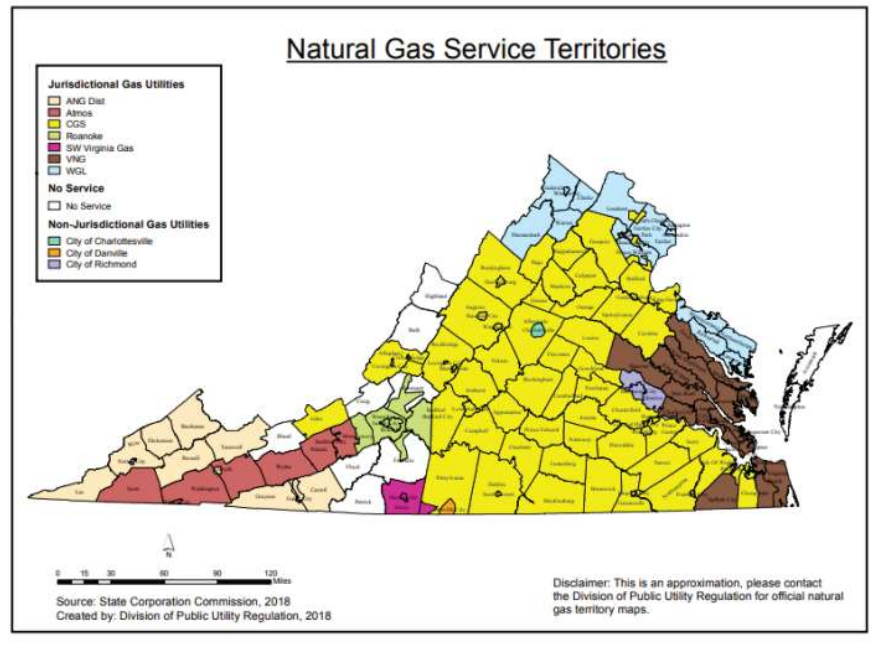
State of Virginia divided into service areas





Problem Statement

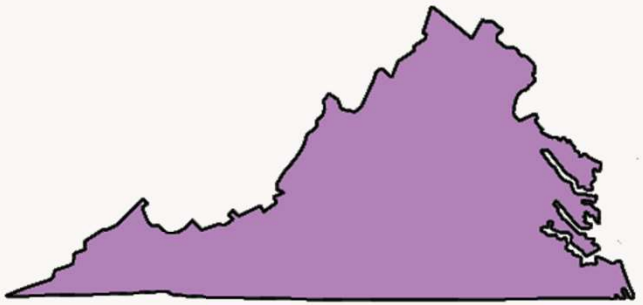




Natural gas consumption data organized hierarchically

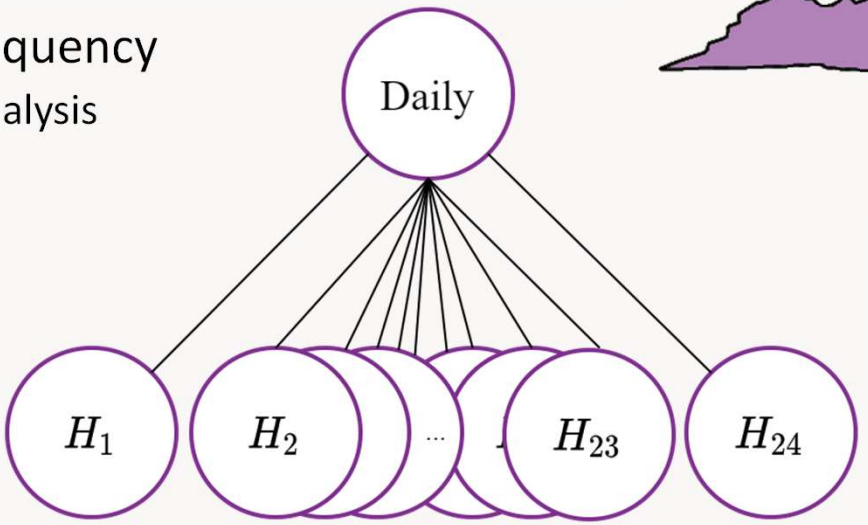
- Two approaches to organizing data hierarchically
  1. Cross-sectional
  2. **Temporal**

State of Virginia- Single Service Area



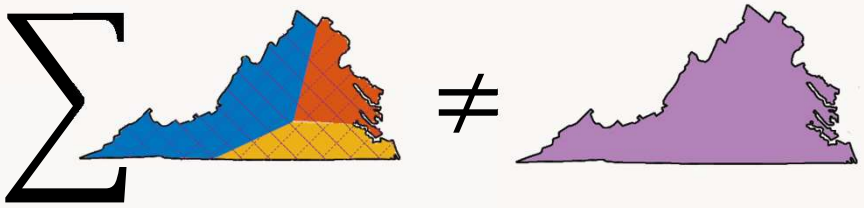
Temporal hierarchy

- Ex: low ←→ high frequency
  - Locked to the unit of analysis

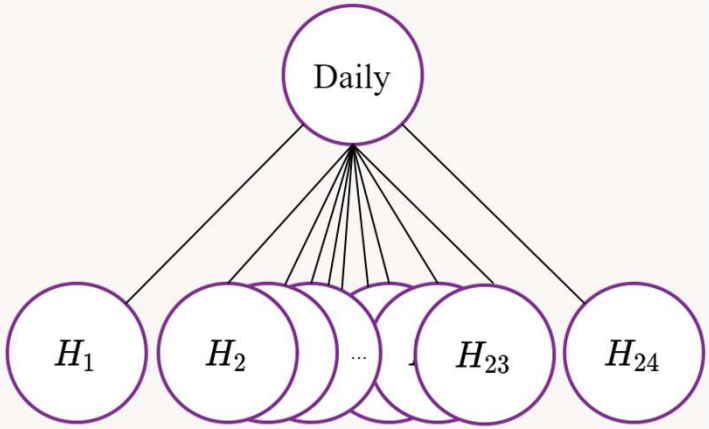


Hierarchical Time Series Forecasting

- In general, forecasts are not **coherent**



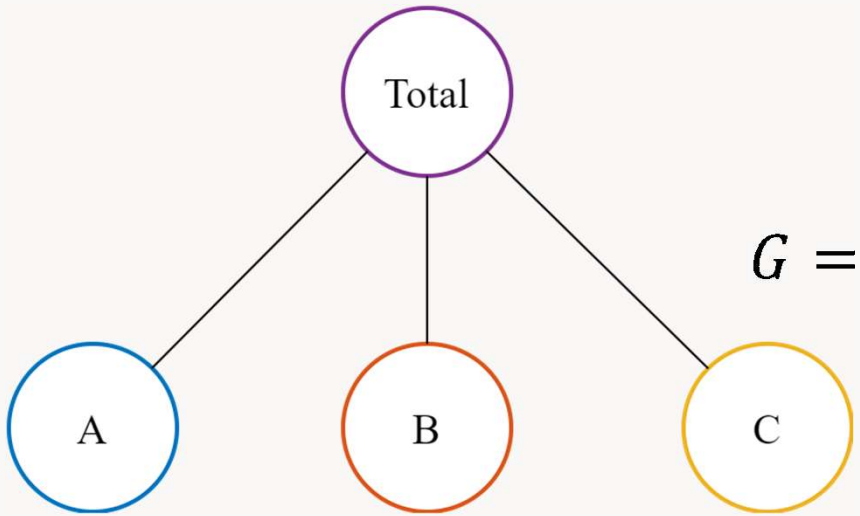
- **Forecast reconciliation** is the process of adjusting forecasts to make them coherent
- Base forecasts at each level can be estimated uniquely



- Current domain
  - Early developments – statistical or judgmental forecasting
    - Bottom Up, Top Down, Middle Out
  - Past decade – linear combination approaches
    - Exploit information from the complete hierarchy to produce more accurate forecasts
  - In development – nonlinear combination approaches

Hierarchical framework for natural gas demand forecasting

- Optimal forecast reconciliation (Hyndman et al., 2019)
  - Minimizes the forecast error of the set of coherent forecasts
  - $b = (A, B, C)'$
  - $y = (y_{tot}, y_A, y_B, y_c)$
  - $y = Sb$
- Summation matrix
- $S = \begin{matrix} 1 & 1 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$



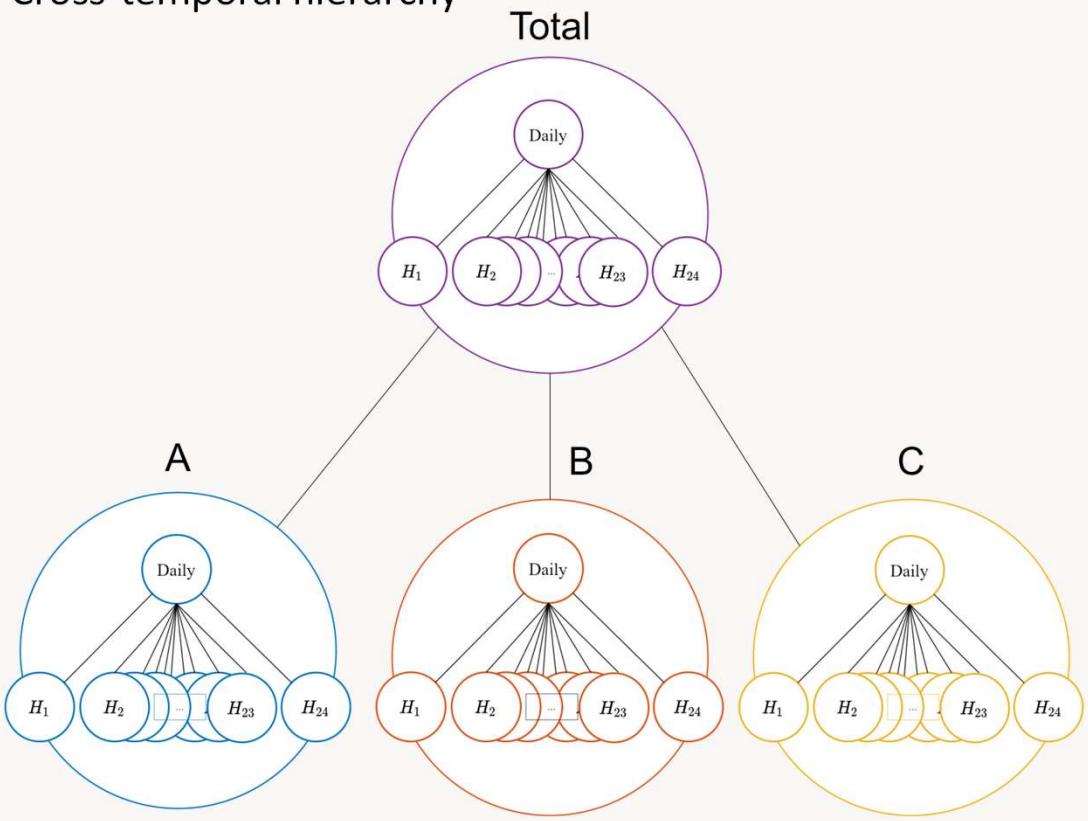
$$\tilde{y}_h = SG\hat{y}_h$$

$$G = \left(S'W_h^{-1}S\right)^{-1}S'W_h^{-1}$$

- $\hat{y}_h$: h step ahead forecasts for y

Cross-temporal hierarchy for gas demand forecasting

- Forecast coherency in a natural gas distribution company setting
  - Cross-temporal hierarchy

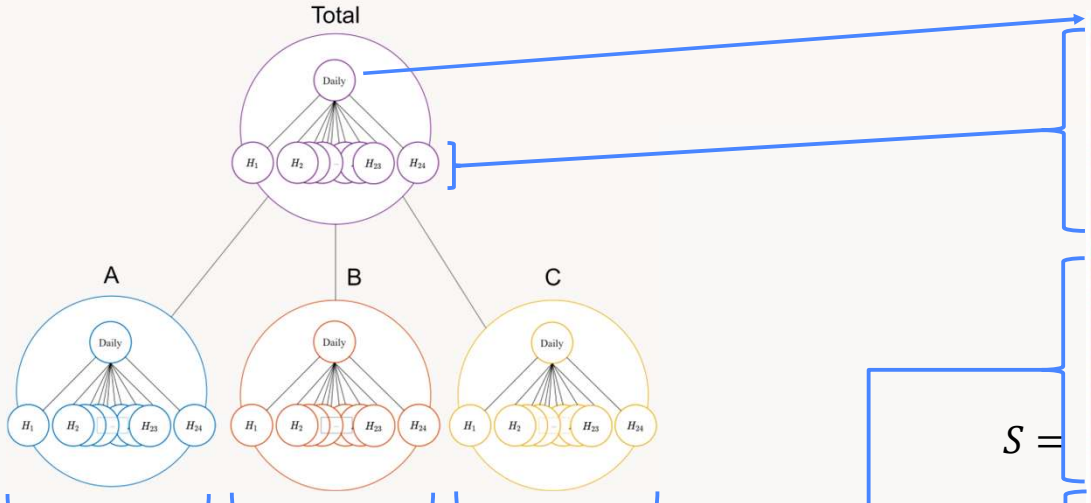


$$b = \left(A_{Hourly}, B_{Hourly}, C_{Hourly}\right)'$$

$$y = Sb$$

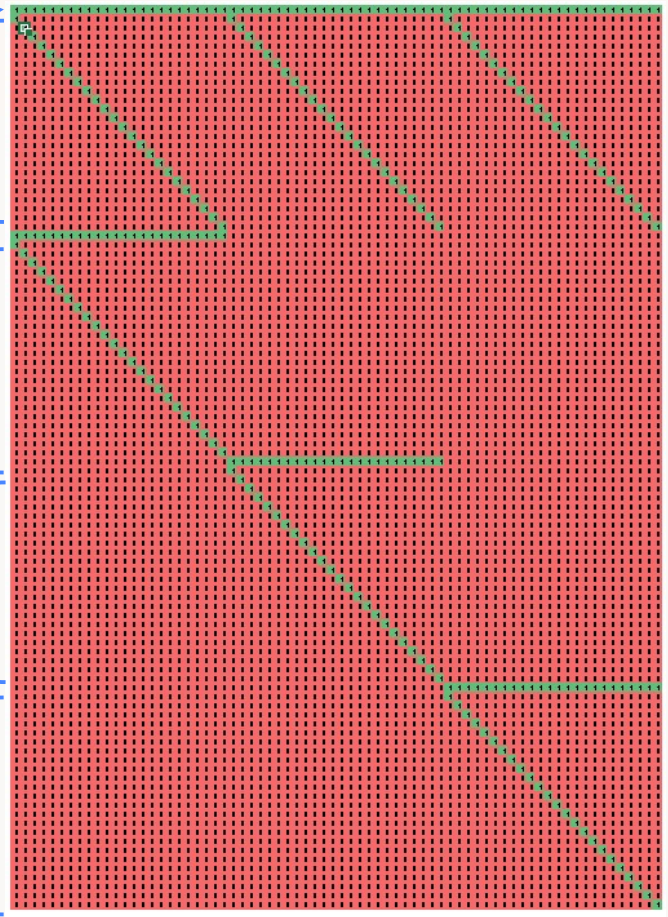
$$\begin{bmatrix} y_{tot_{Daily}} \\ y_{tot_{Hourly}} \\ y_{A_{Daily}} \\ y_{A_{Hourly}} \\ y_{B_{Daily}} \\ y_{B_{Hourly}} \\ y_{C_{Daily}} \\ y_{C_{Hourly}} \end{bmatrix} = S * \begin{bmatrix} A_{Hourly} \\ B_{Hourly} \\ C_{Hourly} \end{bmatrix}$$

Cross-temporal hierarchy for gas demand forecasting



$$\begin{bmatrix} y_{tot_{Daily}} \\ y_{tot_{Hourly}} \\ y_{A_{Daily}} \\ y_{A_{Hourly}} \\ y_{B_{Daily}} \\ y_{B_{Hourly}} \\ y_{C_{Daily}} \\ y_{C_{Hourly}} \end{bmatrix} = S * \begin{bmatrix} A_{Hourly} \\ B_{Hourly} \\ C_{Hourly} \end{bmatrix}$$

$S =$



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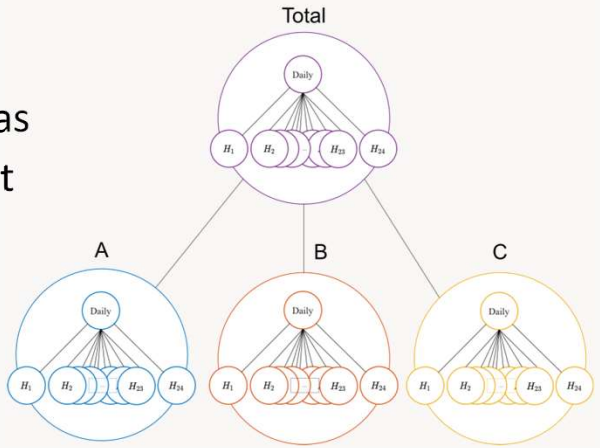
Our cross-temporal Hierarchy

$$\tilde{y}_h = SG\hat{y}_h$$

$$G = \left(S'W_h^{-1}S\right)^{-1}S'W_h^{-1}$$

- Cross-temporal approach
  - Aspects locked by time and unit of analysis
  - Unbiased quality maintained
- Advantages
  1. Point forecasts are reconciled across all levels of the hierarchy
     - In our case, reconciled across planning horizons and gas service areas
  2. Intra-hierarchy level interactions and correlations taken into account
     - Plan from long- to short-term horizons
  3. Ad hoc adjustments
     - Base forecasts
  4. Forecast uncertainty
- Construction of S and G is nontrivial and computationally demanding



Cross-temporal hierarchy: case study

- The proposed method is evaluated using Average Relative Mean Squared Error ($AvgRelRMSE$)

$$RelRMSE = \frac{RMSE_{Hierarchial}}{RMSE_{Base}} \qquad AvgRelRMSE = \sqrt{\sum_{i=1}^{n} RelRMSE}$$

n = number of time series

- $AvgRelRMSE$ < 1
- Error evaluated over 3-year period
- Total level
- Base forecasts 2-years
- Errors measured across time are calculated using the geometric mean

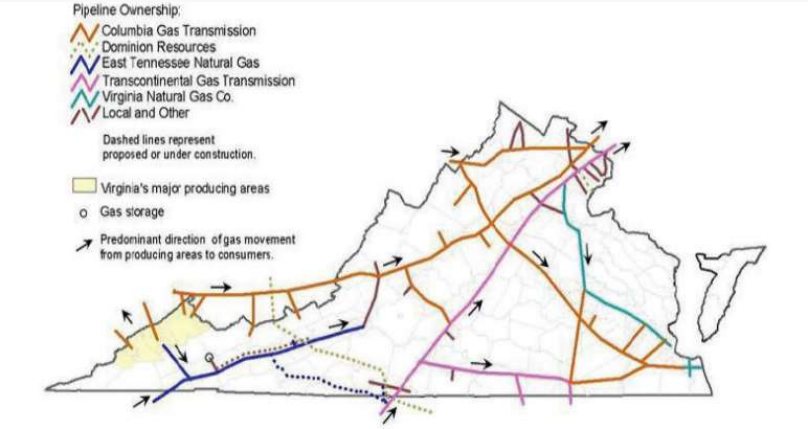
Results

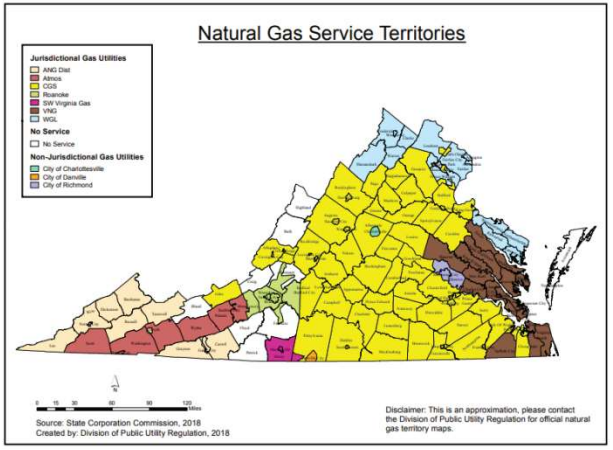
	$AvgRelRMSE$	
Unit of Analysis	**Reconciliation method**	$\boldsymbol{AvgRelRMSE}$
Temporal	Base	1.000
	MinT	0.973
	Bottom Up	0.986
	Top Down	0.991
Spatial	Base	1.000
	MinT	0.961
	Bottom Up	0.977
	Top Down	0.984
Cross-temporal	Base	1.000
	MinT	**0.927**
	Bottom Up	0.939
	Top Down	0.942

- Total level
- Grouped by Unit of Analysis
- $AvgRelRMSE < 1$
- Cross-temporal approach shows promise
  - Temporal results – averaged geometric mean
- Bottom up and Top Down

Next steps

- Feasibility of hierarchical forecasting in deep-temporal natural gas demand setting
  - Include more hierarchies (res, non res, …)
  - Estimation of variance-covariance matrix W
- Different levels of gas distribution organization and time horizon of concern
  - Hourly, daily, monthly
- Improve base forecasts over 6-parameter model





Questions?

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Thank you.

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