Electrification in the Long Run

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Motivation: Climate change requires substantial transformation of electricity sector

- Electrify everything
  - Space heating in homes: 22 percent increase in electricity load
  - Light duty vehicles: 21 percent increase in electricity load
- Technological changes
  - Renewables and Storage
  - EVs, Heat pumps, hydrogen generation
- Electricity sector of future may look nothing like today

This Paper

- Develop long run model of electricity sector and electrification
  - No fixed inputs or legacy plants: completely rebuild the grid
  - Focus on long-run equilibrium (not transition dynamics)
  - Theoretical results
  - Calibrated model illustrates relevance of theory results and additional insights

Preview of Findings

- Theory Results
  - Electrification may decrease total emissions from the grid (negative emissions)
  - Electrification may decrease renewables (supra-max emissions)
  - Cheaper storage can drive out renewables
- Calibration: Divide US into 13 electricity regions
  - Negative emissions most likely to occur for electrification that increases demand on summer days
  - EV charging timing matters a great deal (can get negative emissions or supra-max emissions)

Model: Overview

- Long run competitive equilibrium model with capacity investment
- No explicit dates, but fixed unit of time (year)
- T periods within the year (hours)
  - Model does not have explicit uncertainty
  - But in each period t there is different value of electricity demand, sun, and wind
  - Interpretation: agents have perfect foresight about the distribution of these variables
- Electricity produced by I different techs (Sun, Wind, Gas, Nuclear,...)

Model Details: No Storage

$$\max_{Q_t, q_{it}, K_i} \sum_t [U_t(Q_t) - \sum_i c_i q_{it}] - \sum_i r_i K_i$$

Endogenous choice of

- Q_t consumption
- q_{it} generation by tech
- K_i capacity by tech

Constraints

- System Balance $Q_t = \sum_i q_{it}$
- Generation $q_{it} \leq f_{it} K_i$

Technology i has

- Constant marginal cost c_i
- Unit capital cost r_i
- Capacity factor f_{it}

Model Details: With Storage

$$\max_{Q_t, q_{it}, b_t, S_t, K_i, \bar{S}} \sum_t [U_t(Q_t) - \sum_i c_i q_{it}] - \sum_i r_i K_i - r_s \bar{S}$$

Additional endogenous choice of

- b_t battery charge
- $\bar{S}$ battery capacity
- S_t battery state

Battery has

- Unit capital cost r_s

Constraints

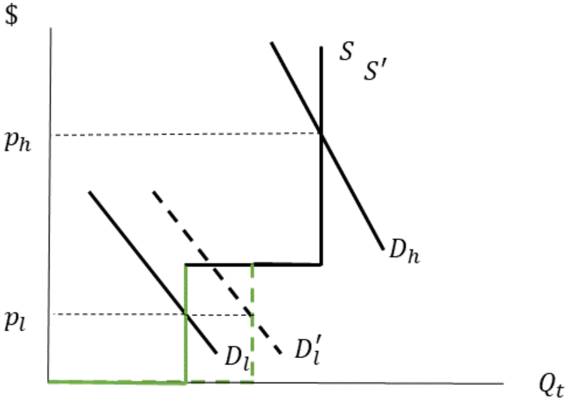
- System Balance is now $Q_t + b_t = \sum_i q_{it}$
- Battery $S_t = S_{t-1} + b_t$ and $0 \leq S_t \leq \bar{S}$.

Electrification

- E_t is electricity consumption from activity that switches from fossil fuels to electricity
- Assume exogenous (avoid taking stand on change in CS)
- System balance is now $Q_t + b_t + E_t = \sum_i q_{it}$.
- Define *electrification* as ΔE_t (typically from zero).
- Let β_i be emissions rate for tech i
- Long run emissions change (LREC) defined as

$$\frac{\sum_i \sum_t \beta_i \Delta q_{it}}{\sum_t \Delta E_t}.$$

Theory Result 1: Electrification can reduce emissions



Notes: Two periods: *h* and *l*, and two technologies: renewable (1, green) and fossil (2, black). Electrification in period *l* decreases emissions.

Calibration: Data and Parameters

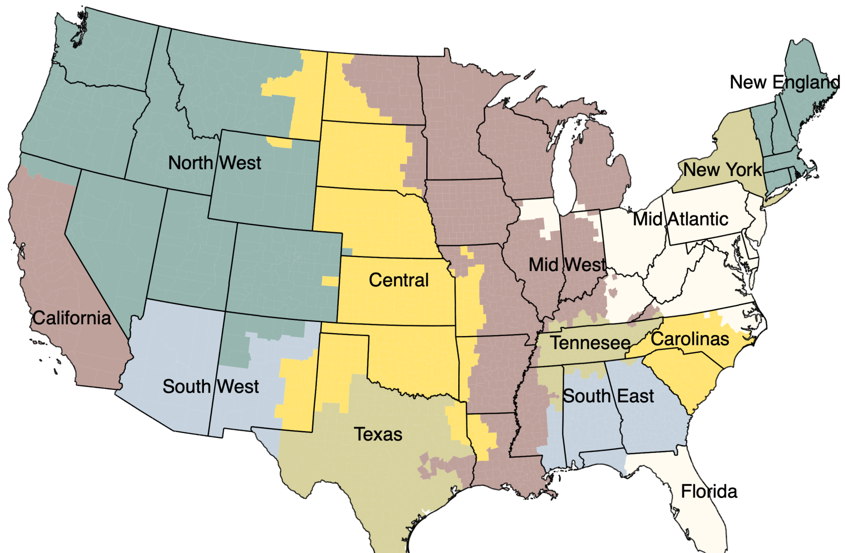
Table: Capital and Operating Costs for Different Technologies

	Annual Capital Cost $ per MW	Marginal Operating costs $ per MWh	Carbon Emissions tons/MWh
Gas Combustion Turbine	54,741	44.13	0.526
Gas Combined Cycle	79,489	26.68	0.338
Advanced Nuclear	528,307	2.38	0
Wind (onshore)	132,602	0	0
Solar PV	83,274	0	0
Battery Storage	18,935	0	0

Notes: Source EIA "Table 1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2026 (2020 dollars per MWh)".

Calibration: Data and Parameters

We use 13 electricity regions



Calibration: Data and Parameters

To determine demand (U_t') we

- Assume linear demand curves with elasticity = -0.15
- Obtain hourly quantities from EIA 930, reference prices from SNL and FERC 714 lambas

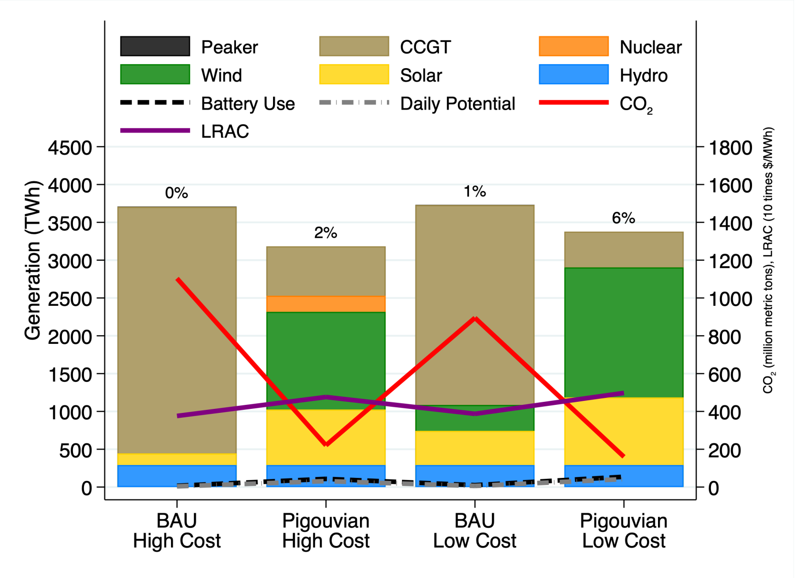
To determine capacity factors (f_{it}) we

- Obtain wind and solar capacity (from EIA 860) and hourly generation (from EIA 930)

Results: 2 x 2 classification

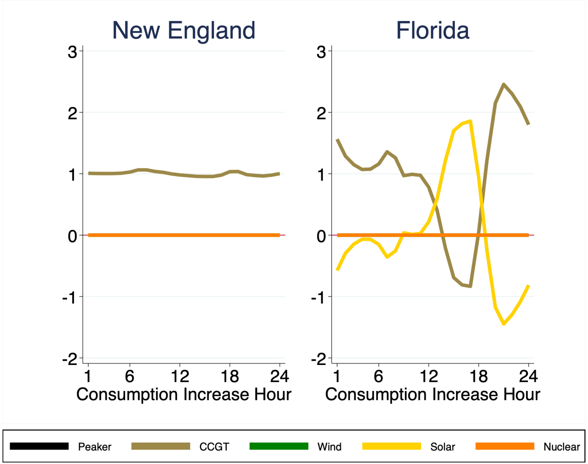
- Capture differing policy and innovation
- BAU High Cost: No carbon tax, baseline renewable costs
- BAU Low Cost : No carbon tax, 25 percent reduction in renewable costs
- Pigouvian High Cost: Carbon tax, baseline renewable costs
- Pigouvian Low Cost : Carbon tax, 25 percent reduction in renewable costs
- Assume SCC = $100

Results: No Electrification



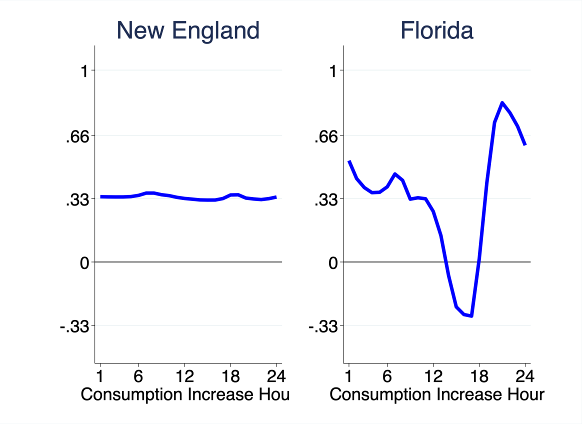
Electrification: small increase in consumption in one hour

- Every day, at hour *h*, load increases by 1 unit
- BAU Low Cost case
- What happens to generation?

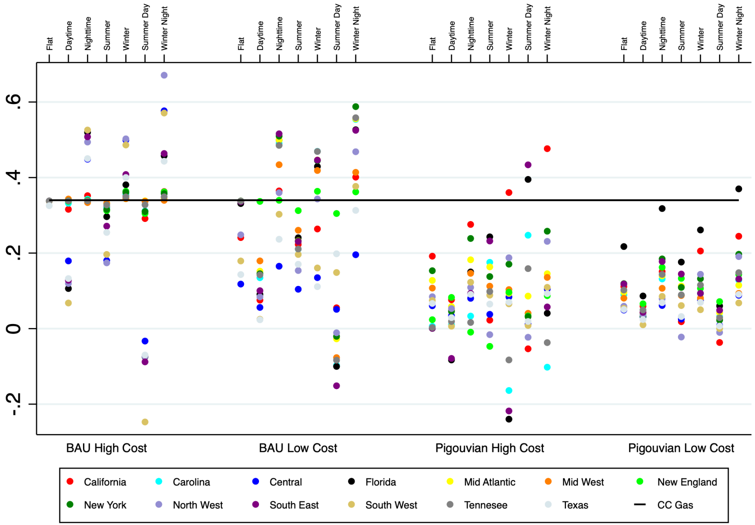


LREC for small increase in consumption in one hour

- Both negative and supra-max emissions are possible



LREC for small increase in consumption in multiple hours

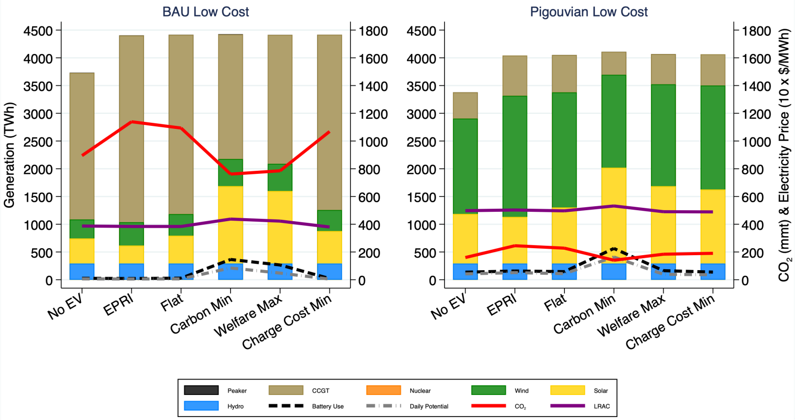


Electrification: Light duty vehicle fleet

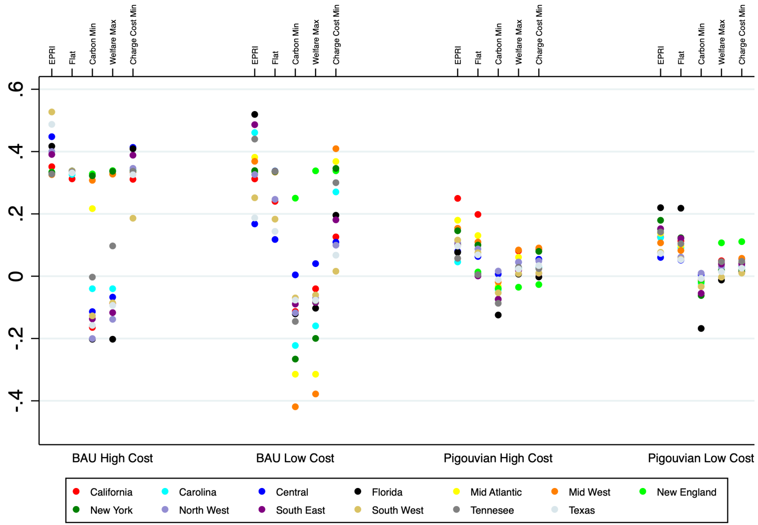
- Replace all light duty gasoline vehicles with EVs
- When are they charged?
  - EPRI - mostly at night, consistent with Burlig et al 2021.
  - Flat - evenly spaced over all hours
  - Carbon Min
  - Welfare Max
  - Charge Cost Min

Electrification: Light duty vehicle fleet

- Possible negative emissions (no gas vehicle emissions and lower electricity emissions)
- Timing matters (charging during the day induces solar).
- Place chargers at shopping areas and workplaces rather than apartments?



LREC's for light duty fleet electrification



Conclusion

- Model and calibration illustrates that long run effects can differ in surprising ways from short run analogs.
- Emissions effect in short run may be different than in long run. When is best time to charge EV?
- Simple and transparent model useful supplement to literature. Allows integration of theory results.