Investment and the Transfer of Power: Dynamic Effects of Transmission in Electricity Markets

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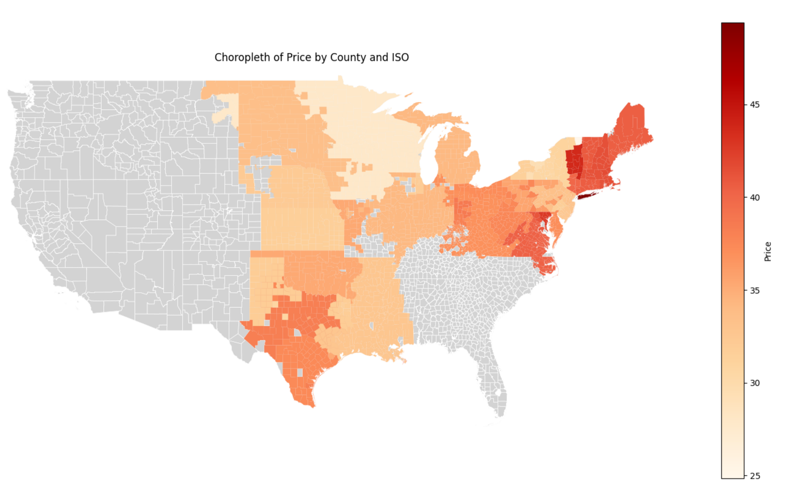
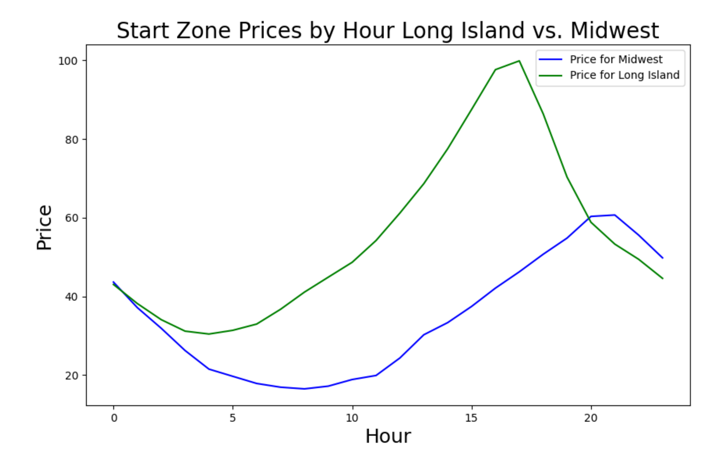
Motivation

- Renewable resources intermittent and dispersed
- Storage of electricity difficult and cost prohibitive
- Not all areas have strong renewable potential
- Long-range transmission has started to emerge as a solution
- Limited prior investment in long-range transmission

Data Feature: Prices and Renewables Vary with Space and Time



(a) Price Dispersion in Space.



(b) Price Dispersion Space and Time.

Research Questions

1. What are the impacts of transmission constraints on price?
2. If market frictions in long-distance trading of electricity decreased, how would this impact capacity investment?
3. How would increases in transmission affect reliability and emissions?
4. What would be the impact of the Big Wires Act?

Data Construction Process

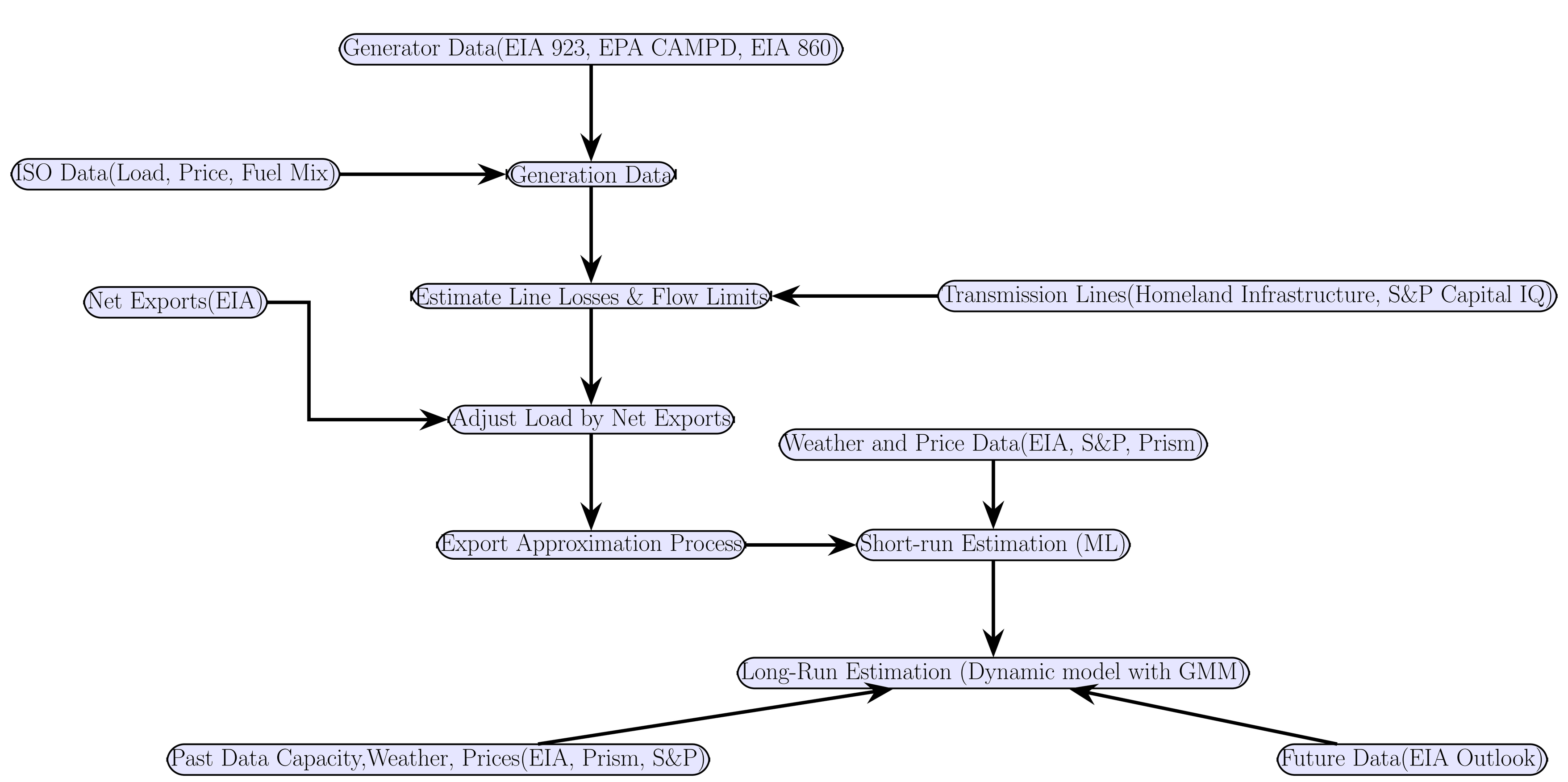
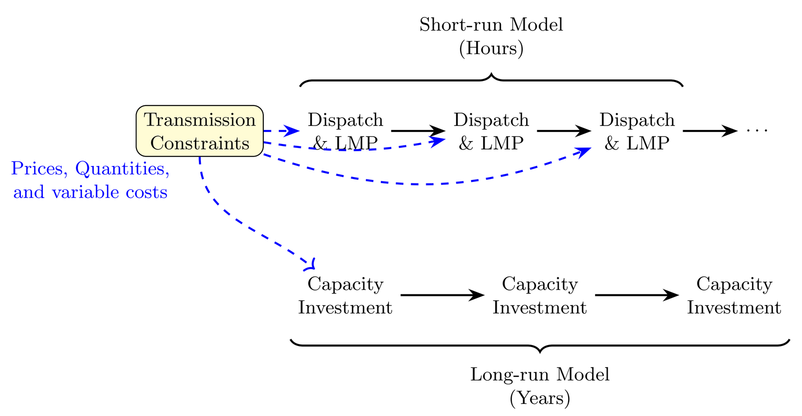
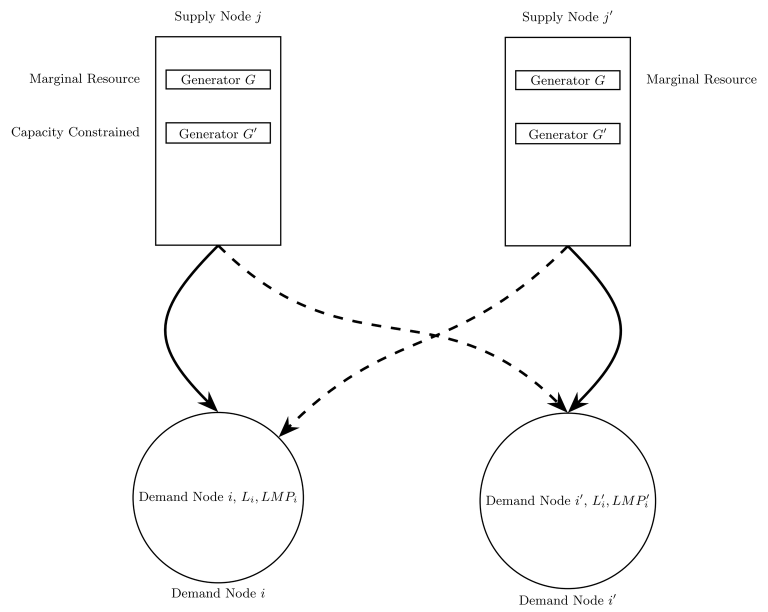


Figure 2. Data Construction Diagram.

Model Primitives: Short-run feeds Long-Run

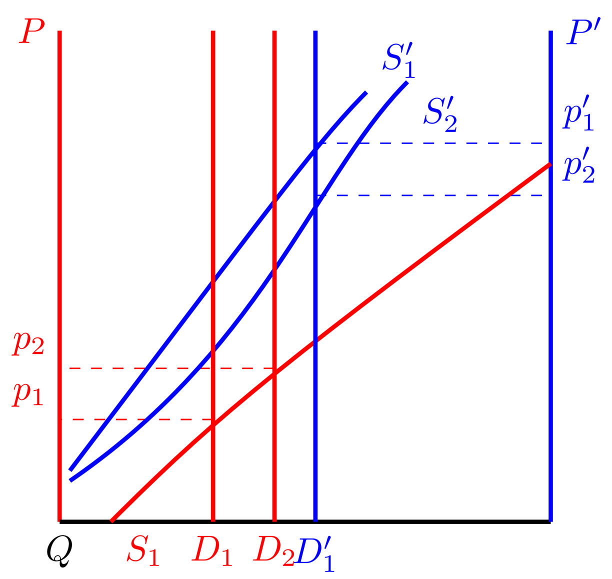


(a) Model Timeline.

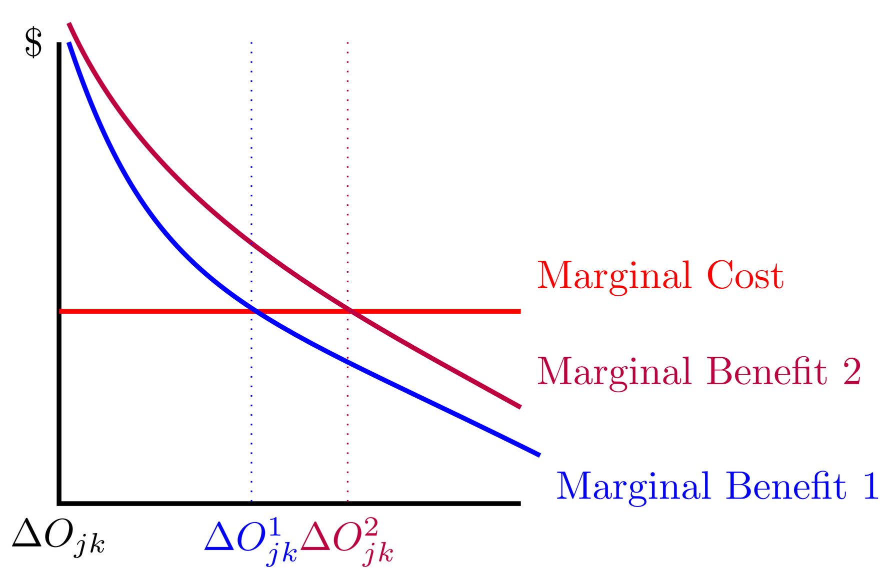


(b) Network Example.

Model Graphically: Trade equalizes prices



(a) Short-run Model.



(b) Long-run Model.

Short-run Model Mathematically

- Short-term Model: ISOs minimize cost to satisfy all retail demand L_{it} at each node i

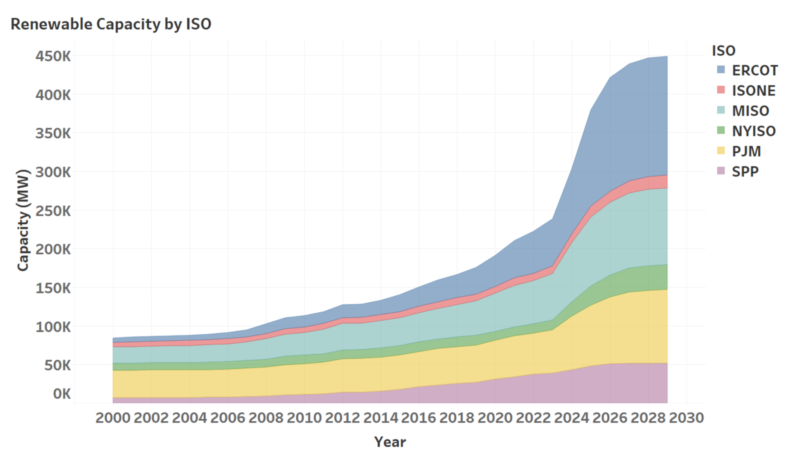
$$\pi_t = \max_{\{q_{ijkgt}\}_{i,j,k,g,t\in I,J,K,G,T}} [-\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{g=1}^{G} c_{jkgt}(x_{jkgt}, q_{ijkgt}, \epsilon_{ijkgt})] s.t. \quad (1)$$

$$\underbrace{\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{g=1}^{G}(1-B_{ij})q_{ijkgt} = L_{it}\,\forall i}_{\text{Resource constraint}}$$

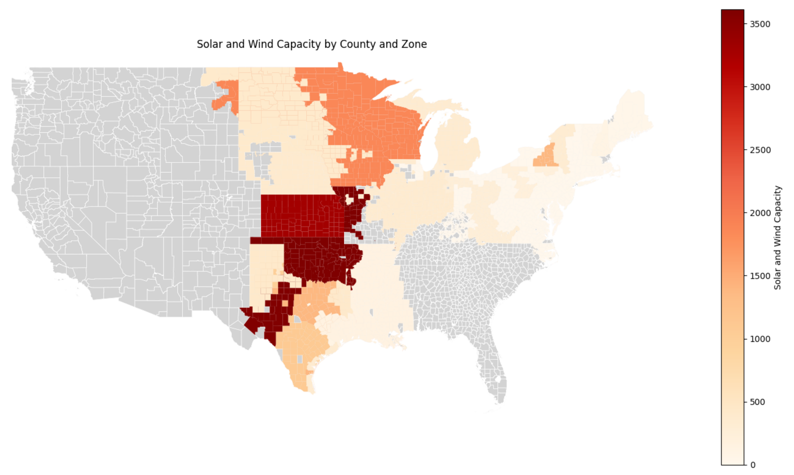
$$\underbrace{\sum_{k=1}^{k}\sum_{g=1}^{G} q_{ijkgt} \leq A_{ij}\,\forall i,j,t}_{\text{Transmission constraint}}$$

$$\underbrace{0 < \sum_{i} q_{ijkgt} \leq O_{jkgt}^{MAX}\,\forall j,k,g,t.}_{\text{Capacity constraint}}$$

Data Feature: Growth of Renewables over Time



(a) Different investments by ISOs.



(b) Midwest dominates renewable investment.

Long-run Model Mathematically

- Long-term model: Generators invest in generation capacity to maximize profits

$$v_{gt}(\Theta) = \max_{\Delta O_g} \sum_j \Pi_{jg}(\Theta) + \varepsilon_{jg}(\Delta O_{jg}) + \beta \mathbb{E} v_{jgt+1}(\Theta') \quad s.t. \quad (2)$$

$$\Pi_{jg} = \sum_k [\underbrace{D_{jkg}(d_{jkg}, O_{jkg}, O_{jkg}^{-})P_{jkg}}_{\text{Revenue}}$$

$$\underbrace{- C_{jkg}(d_{jkg}, O_{jkg}, O_{jkg}^{-})D_{jkg}(d_{jkg}, O_{jkg}, O_{jkg}^{-}) - F_k O_{jgk} - E_k max(\Delta O_{jgk}, 0)]}_{\text{Costs}}$$

$$\underbrace{O'_{jgk} = O_{jgk} + \Delta O_{jgk}}_{\text{Evolution of capacity}}$$

$$\underbrace{\begin{array}{c} F'_k = \psi_{1k} + \rho_{1k}F_k + \zeta'_{k1}, \zeta_1 \sim N(0, \sigma^2_{\zeta_1}) \\ E'_k = \psi_{2k} + \rho_{2k}E_k + \zeta'_{k2}, \zeta_2 \sim N(0, \sigma^2_{\zeta_2}) \end{array}}_{\text{Evolution of costs}}$$

Estimation Strategy

- Short-run Estimation
- Find transmission capacities between zones
- Solve Lagrangian for Euler equations
- Use zero shadow prices at central resource locations to solve for shadow prices at other locations and resources
- Isolate and solve for errors
- Perform maximum likelihood estimation

- Long-run Estimation
- Utilizes Erikson-Pakes (1995) estimation procedure for dynamic games
- Combines with Gowrisankaran, Schmidt-Dengler (2024) procedure for reducing choice candidates in dynamic capacity games
- Uses generalized method of moments to estimate parameters

Conclusions and Next Steps

- Conclusions
  - The renewables transition requires an improved grid
  - Long-distance transmission equalizes prices and provides price insurance
  - Improving transmission has static and dynamic effects on markets
- Next Steps
  - Estimate short-run likelihood function using Jax
  - Estimate long-run model using GMM and Gowrisankaran, Schmidt-Dengler (2024)
  - Run counterfactuals