Ramping Up Renewable Energies – the Role of Ramping Cost and Energy Storage

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Renewable Energy & Energy Storage

Renewable energy $\Uparrow$

- Intermittent: "variable" supply
- increase electricity price volatility

Energy storage $\Uparrow$

- arbitrage price difference
- smooth out electricity price volatility

Power Plant Flexibility

Renewables/energy storage affects power plants differently

- Plants with large output adjustment cost benefits (hurts) more from price smoothing (variation)

Power plant's output adjustment costs:

- **Start-up** Cost: Cost of output adjustment from 0 to > 0
- **Ramping** Cost: Cost of $(+/-)$ output (excluding + output from 0)

Traditional Renewables/energy storage evaluation studies

- Ignores output adjustment cost $\Rightarrow$ biased estimates on production cost, output and emissions
- Cullen (2015): models start-up cost, but not ramping cost

Research Goal

- Estimate ramping cost for power plants
- (Dis)Investment signals to power plants under different renewable/energy storage configurations
- Incorporate both ramping cost and start-up cost into renewable/energy storage evaluation

Model

Per-period (hourly) profit function:

$$\pi = \begin{cases} (p_t + \eta_t)q_t - \alpha_1 c(q_t) - \alpha_2(q_t - q_{t-1})^2 - \alpha_3(1 - d_{t-1}), & d_t = 1 \\ -\alpha_2 q_{t-1}^2, & d_t = 0 \end{cases}$$

- p_t: electricity price
- η_t: unobserved component in real price received
- q_t: electricity output
- $c(q_t)$: heat input (quadratic)
- d_t: operating status
- α_2: **ramping cost**; α_1: production cost; α_3: start-up cost

Feasible Output Range: $q_t \in \{0\} \cup [\underline{q}, \bar{q}] \Rightarrow$ Corner solutions (for a dynamic problem)

Estimation: Euler Equation for Interior Points

Challenge: selection bias due to unobserved η_t:

$$E\left\{p_t - \alpha_1 c'(q_t) + \alpha_2\left[2\beta q^*_{t+1} - (2\beta+2)q^*_t + 2q_{t-1}\right]\right\} + E\left\{\eta_t | 1(q_t \in int)\right\} = 0$$

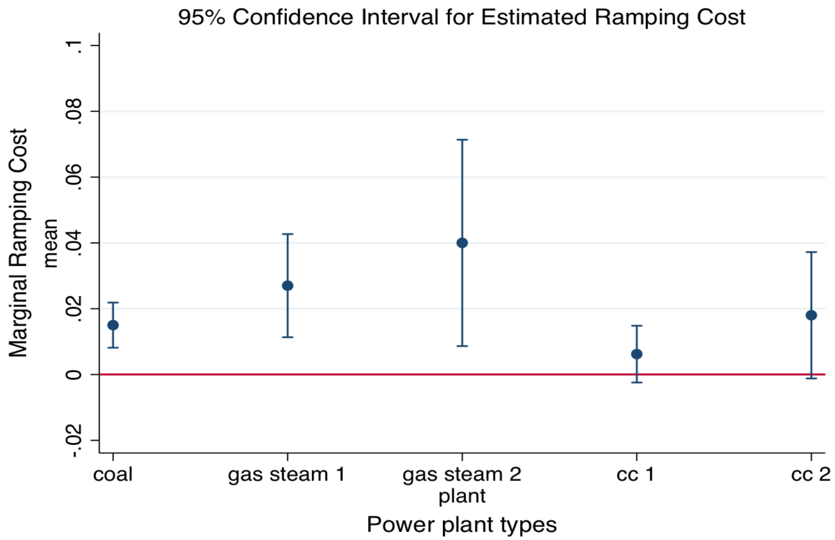
- Arguirregabiria (1997): express selection term as a known function of reduced-from probabilities
- Then standard GMM follows

Data

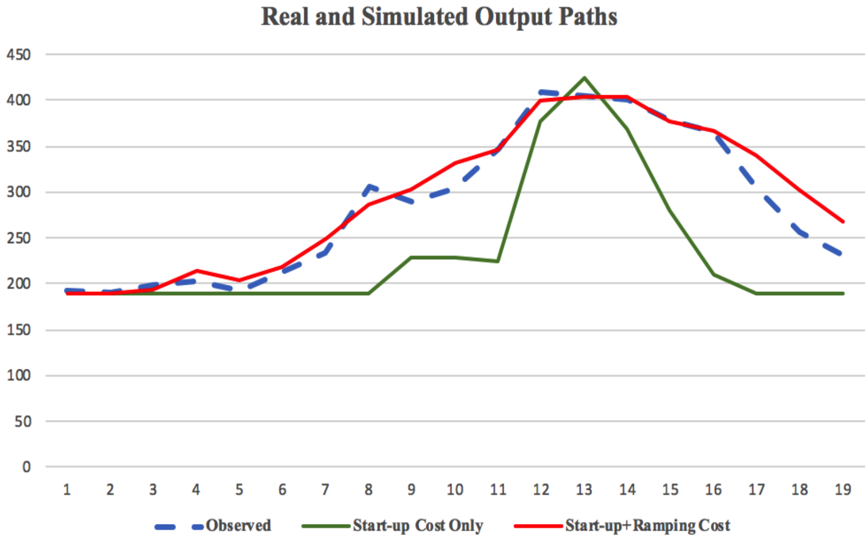
Information on ERCOT 2015, the Texas grid, is used in the study

- ERCOT – Hourly net output of each generator, hourly electricity price and hourly aggretate wind power generation in the region
- CEMS – hourly heat input of each generator
- 8760 hours for each generator
- West load zone: 1 coal-steam, 2 gas-steam, and 4 combined-cycle gas plants

Ramping Cost Estimates



Goodness of Fit



Importance of Ramping Cost

Without considering ramping cost (only considering start-up cost), with observed 2015 electricity price path, a coal plant's

- Total profit was overestimated by 15%
- Total output (and emissions) was underestimated by 10%

The biases are larger for plants with larger ramping cost

Ongoing

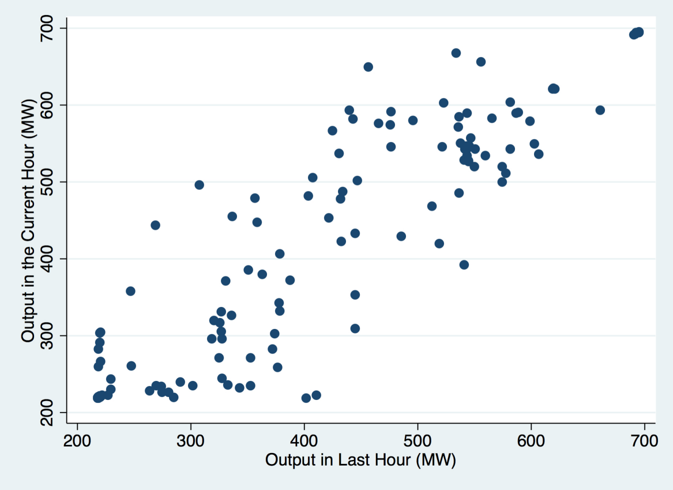
Policy simulations are running right now

- Non-marginal increase in Wind energy
- Non-marginal increase in energy storage
- Mix wind energy with solar energy

Calculate the impact of such changes on total social welfare (production cost and emission damages)

Suggestions Welcomed!

Data: Evidence of Ramping Cost



Ramping Cycles