Start-up Costs and Market Power: Lessons from the Renewable Energy Transition
Jha & Leslie (2025)

Dongchen He

Environmental Reading Group

September 8, 2025

The Economics of Renewable Energy

- The large-scale expansion of **rooftop solar** has fundamentally changed the economics of wholesale electricity markets.
- Solar has a near-zero marginal cost, which allows it to **crowd out fossil fuel power plants** during the sunny hours of the day.
- As a result, fossil fuel plants must frequently stop and restart their operations, especially to meet demand in the evening after solar generation fades.

Research Question and Motivation

- **Motivation:** Conventional measures of market power (e.g., markups over short-run marginal cost) often fail to account for the dynamic fixed costs that firms incur to enter and exit production. In a market with intermittent renewables, fossil fuel plants must frequently stop and start, incurring significant **start-up costs**.
- This complicates the analysis of market power. We need to know if firms are profiting from genuine market power or simply recovering their fixed costs.
- **Research Question:** What is the difference between traditional static measures of market power and the dynamic considerations introduced by start-up costs?

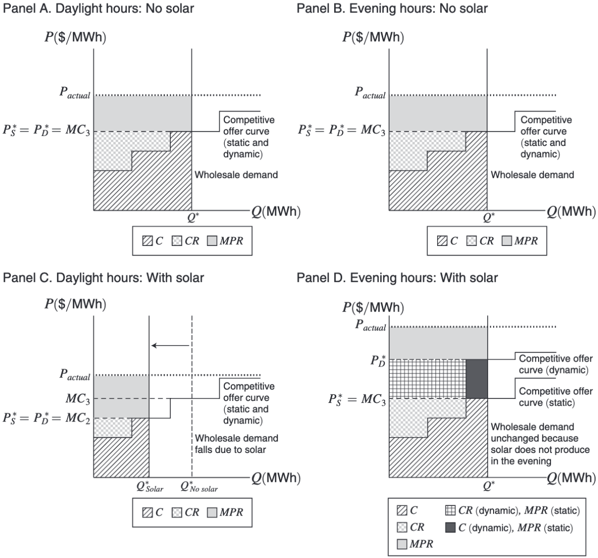
Key Findings (Preview)

- Traditional static markups can significantly **overstate** market power in a dynamic market with start-up costs (dynamic competitive price is 21% than static competitive price.).
- The expansion of rooftop solar can **increase the collective profitability** of fossil fuel plants.
- This increase is due to **softening competition at sunset**, when solar output declines and fossil fuel plants with lower marginal costs must incur higher start-up costs to re-enter the market.
- The increase in profitability is primarily driven by the **increased exercise of market power in the evening peak**, not by an increase in the competitive price benchmark.

Study Setting: Western Australia

- The authors use data from **Western Australia (WA)**.
- The data covers the period from 2014 to 2018, during which rooftop solar capacity roughly doubled.
  - No inter-regional transmission constraints.
  - No fossil fuel capacity change.
  - No much wind capacity and large-scale solar.

Conceptual Framework: Static vs. Dynamic



Datasets Used (2014–2018)

- Wholesale electricity demand, prices, and dispatch (AEMO, WEM South West Interconnected System)
- Half-hourly rooftop solar output and monthly capacity (Australian PV Institute)
- Monthly rooftop solar installations (Clean Energy Regulator)
- Daily natural gas use (Gas Bulletin Board of Western Australia)
- Quarterly coal and gas prices (WA Department of Mines and Petroleum)
- Unit-level generation capacity, outages, and ancillary services (AEMO)
- Non-fuel start-up cost estimates (Kumar et al. 2012, engineering data)

Dynamic Production & Cost Equations

$$\textbf{(1)} \quad G_{i,t} = \alpha_i^V O_{i,t} + \alpha_i^S \mathbf{1}\{O_{i,t} > 0,\ O_{i,t-1} = 0\} + \alpha_i^R \mathbf{1}\{O_{i,t} > 0\} + \varepsilon_{i,t} \tag{1}$$

$$\textbf{(2)} \quad \sum_{t=1}^{48} G_{i,t} = \alpha_i^V \sum_{t=1}^{48} O_{i,t} + \alpha_i^S \sum_{t=1}^{48} \mathbf{1}\{O_{i,t} > 0,\ O_{i,t-1} = 0\} + \alpha_i^R \sum_{t=1}^{48} \mathbf{1}\{O_{i,t} > 0\} + \sum_{t=1}^{48} \varepsilon_{i,t} \tag{2}$$

$$\textbf{(3)} \quad TC_{i,t} = P_t^{NG}\, \widehat{G}(O_{i,t},\ O_{i,t-1}) + VOM_i\, O_{i,t} + SOM_i\, \mathbf{1}\{O_{i,t} > 0,\ O_{i,t-1} = 0\} \tag{3}$$

$G_{i,t}$: gas burned; $O_{i,t}$: electrical output; $\widehat{G}(\cdot)$: predicted gas use from (1); P_t^{NG}: gas price; VOM_i: nonfuel variable O&M; SOM_i: nonfuel start-up cost; $\mathbf{1}\{\cdot\}$: indicator.

Dynamic Benchmark: Cost Minimization

Objective:

$$\min_{\{O_{i,h}\}} \sum_{h=1}^{48} \sum_{i=1}^{G} \Big(P^{NG} \alpha_i^V O_{i,h} + VOM_i O_{i,h} \\ + P^{NG} \alpha_i^S \mathbf{1}\{O_{i,h} > 0, O_{i,h-1} = 0\} + SOM_i \mathbf{1}\{O_{i,h} > 0, O_{i,h-1} = 0\} + P^{NG} \alpha_i^R \mathbf{1}\{O_{i,h} > 0\} \Big) \tag{4}$$

Constraints:

$$\sum_{i=1}^{G} O_{i,h} = RD_h \quad \forall h \qquad \text{(Residual demand)} \tag{5}$$

$$O_{i,h} - O_{i,h-1} \leqslant \overline{M}_i(S_i) \quad \forall (i,h) \qquad \text{(Ramping)} \tag{6}$$

$$O_{i,h} \in \{0\} \cup [\underline{K}_i, \overline{K}_i] \quad \forall (i,h) \qquad \text{(Min/Max output)} \tag{7}$$

$$O_{i,h} \in [\underline{K}_i^{AS}, \overline{K}_i^{AS}] \text{ if } AS_{i,h} = 1 \qquad \text{(Ancillary service)} \tag{8}$$

$$O_{i,h} \in [\underline{K}_i^{T}, \overline{K}_i^{T}] \text{ if } T_{i,h} = 1 \qquad \text{(Transmission)} \tag{9}$$

Dynamic Benchmark: Pricing

Objective:

$$\min_{\{p_h\}} \sum_{h=1}^{48} p_h D_h \quad \text{(minimize wholesale payments)}$$

Constraints:

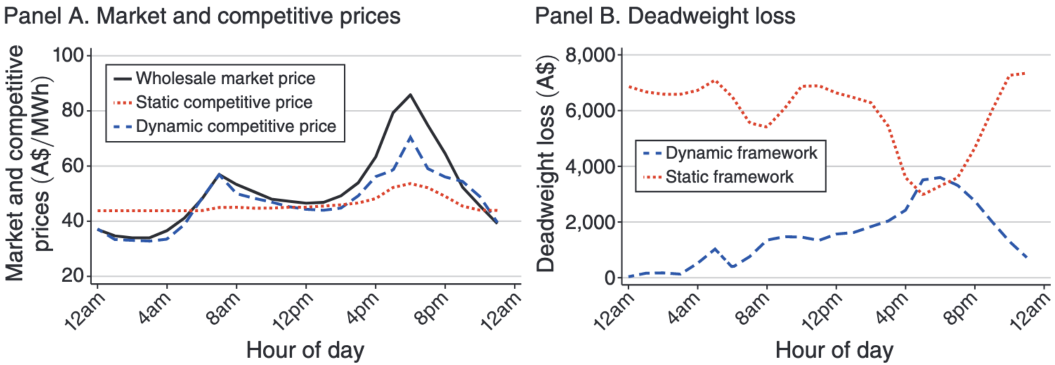
$$\sum_{h=1}^{48} p_h O_{i,h} \geqslant \sum_{h=1}^{48} TC_{i,h} \quad \forall i \qquad \text{(Nonnegative profits)} \qquad (10)$$

$$\Pi(p, O_i) \geqslant \Pi(p, \tilde{O}_i) \quad \forall (i,h) \qquad \text{(No profitable deviation)} \qquad (11)$$

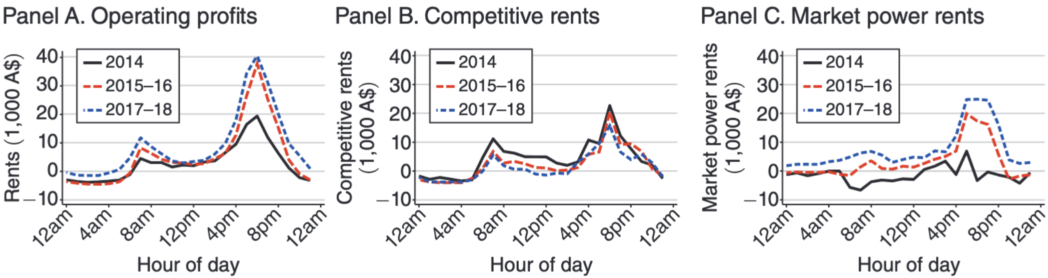
Static rationality condition:

- If $AS_{i,h} = 0$: $\tilde{O}_{i,h} \in \{0\} \cup [\underline{K}_i, O_{i,h}]$ s.t. $O_{i,h+1} - O_{i,h} \leqslant \overline{M}_i(S_{i,h+1})$
- If $AS_{i,h} = 1$: $\tilde{O}_{i,h} \in [\underline{K}_i^{AS}, O_{i,h}]$ s.t. $O_{i,h+1} - O_{i,h} \leqslant \overline{M}_i(S_{i,h+1})$

Benchmark: Static vs. Dynamic



Competitive rents vs. Market power rents



Linking Market Outcomes to Rooftop Solar Penetration

$$Y_t = \alpha + \sum_{h=1}^{48} \sum_{s=0}^{48} \gamma_{h,s} D_{t-s} I_{t,h} + \varepsilon_t, \quad \text{where } I_{t,h} = \mathbf{1}\{\text{half-hour-of-day of } t = h\}. \tag{12}$$

Solar vs. No Solar