Market size and market power:
Evidence from the Texas electricity market

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Consequences of market power

- Inefficient level of production and consumption (Harberger 1954)
- Slower innovation (Aghion et al. 2005)
- Lower quality output (Gaynor & Town 2011)

Economic theory: market structure is primary factor in market power

- Market structure and market power are equilibrium outcomes
- Causal effect is challenging to estimate
- Identification typically requires assumptions on behavior or competition
Exogenous variation in market structure

Novel source of variation in market size: transmission congestion

- Transmission congestion splits the market into “local markets”
- Power plant competes only with other plants in its local market
- Transmission congestion is driven by temperature
- Exogenous variation in market size, cross-sectionally and over time
Research question and results

What is the causal effect of market size on markups?

Empirical strategy: exploit exogenous variation in local market size due to transmission congestion induced by temperature shocks

- 2SLS: instrument for local market size with temperatures
  - Use geographically distant temperatures (\(\sim\) 200 miles on average) that shock the grid without directly shocking the local market

Preview of results

- 10% reduction in market size \(\Rightarrow\) Markups more than double
  - Result driven by competition among fossil fuel-fired capacity
  - Own-firm capacity has large and opposite effect
  - No response to non-fossil capacity (wind, nuclear, etc.)
- $7.1–21.5 million in deadweight loss, $2.1 billion in transfers annually
  - Welfare effects will roughly double due to climate change
Literature and contributions

Competition and market structure

**Empirical relationship**: Bain (1956), Bresnahan (1989)

**Firm entry and exit**: Bresnahan & Reiss (1991), Berry & Reiss (2007)

**Experimental evidence**: Bergquist (2017)

⇒ *Causal effect of market size on markups under weak assumptions*

Wholesale electricity markets

**Market power**: Wolfram (1999), Borenstein et al. (2002), Bushnell et al. (2008)

**Strategic bidding**: Wolfram (1998), Hortaçsu & Puller (2008), Ito & Reguant (2016)

**Transmission**: Borenstein et al. (2000), Davis & Hausman (2016), Ryan (2018)

⇒ *Causal effect of transmission congestion on strategic bidding*
Market power in electricity markets

Electricity markets provide a useful context to study market power

- Homogeneous good
  - No product differentiation concerns

- Perfectly inelastic demand
  - No demand estimation

- Marginal cost is easily calculated
  - No marginal cost estimation

- Market is centralized and clears through auction mechanism
  - No assumptions on nature of competition
Texas electricity market

ERCOT (Electricity Reliability Council of Texas)
- Independent system operator for 90% of Texas
- Schedules the generation and transmission of electricity to ensure a reliable supply
- 570 generating units, 24 million customers, and 46,500 miles of transmission lines
- $12 billion of wholesale electricity annually

Real-time wholesale electricity market
- Firms submit an offer curve for each power plant
- Curves must be submitted one hour before the operating hour
- Algorithm determines dispatch instructions and prices
- Dispatch at lowest cost without violating constraints
Power plants in the Texas electricity market

![Map of Texas electricity market with various power plants marked by different symbols and colors: Natural gas, Coal, Renewables, Nuclear, Other.](image-url)
Offer curve
Market offer curve

Price ($/MWh) vs Quantity (GWh)
Transmission congestion

Transmission infrastructure is sensitive to extreme temperatures

- Thermal expansion causes lines to sag and potentially short circuit
- Increased physical stress causes components to breakdown faster
- Ambient temperature increase from 38°C to 43°C (100°F to 109°F) reduces transmission capacity by 7-8% (Sathaye et al. 2013)
- Demand also increases at high temperatures

What happens when temperature causes transmission congestion?

- Engineers re-optimize the operation of the grid
- Congestion and local markets can form in distant parts of the grid
ERCOT control room

Source: ERCOT
Data

Panel dataset at the power plant-by-hour level for years 2011–2014

Offer curves
- Published by ERCOT after 60 days

Marginal cost
- Constructed using EIA/EPA data on power plant efficiency and emissions, fuel prices, and emissions prices

Local market size
- Constructed from ERCOT data on locational marginal prices

Temperature
- 75 weather stations from NOAA’s Integrated Surface Database
Estimating the effect of market size on market power

Simple but insufficient empirical strategy
- Regress a measure of market power on a measure of market size

Three problems with this naive regression:
- Equilibrium outcomes with no exogenous variation
- Reverse causality in electricity markets
- Prediction problem in this setting

Isolate exogenous but predictable variation in market size
- Solution: instrument for market size with temperature
Temperature as an instrument

Threat to identification: exclusion restriction

- Local temperature may affect many aspects of local market
- Estimate confounds the market size effect with other local temperature-related effects

Solution: use other temperatures throughout the grid

- Transmission grid is a complex network
- Temperature at any point can drive local market formation throughout the grid

I observe hourly temperatures at 75 weather stations in Texas

- I develop a prediction model to match each power plant to the weather station that best predicts the plant's market size

More details
Empirical strategy

Two-stage least squares

\[ Markup_{it} = \beta \hat{Size}_{it} + g(\text{LocalTemp}_{it}) + \gamma_{ihm} + \delta_t + \varepsilon_{it} \]
\[ Size_{it} = f(\text{MatchedTemp}_{it}) + g(\text{LocalTemp}_{it}) + \eta_{ihm} + \theta_t + \omega_{it} \]

- Isolate variation in market size due to temperature variation at matched weather station while controlling for local temperature
- Exploit this exogenous but predictable variation to estimate effects on markups

Identifying assumptions

\[ \text{Cov}(\text{MatchedTemp}_{it}, \text{Size}_{it} | \text{LocalTemp}_{it}, \eta_{ihm}, \theta_t) \neq 0 \]
\[ \text{Cov}(\text{MatchedTemp}_{it}, \varepsilon_{it} | \text{LocalTemp}_{it}, \gamma_{ihm}, \delta_t) = 0 \]
Temperature $> 40^\circ$C ($104^\circ$F) $\Rightarrow$ 12% reduction from mean (53 GW)

- Similar reduction for number of units and firms in a local market

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Temperature-response of markups

Temperature $> 40^\circ C (104^\circ F) \Rightarrow 200\%$ of markups, $600\%$ of marginal cost

- Comparable but smaller increase at lower quantities

- 75\% and 65\%
- Without control
## Effect of market size on markups

<table>
<thead>
<tr>
<th>Local market capacity (GW)</th>
<th>Markup at 85% capacity ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS (1)</td>
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<tr>
<td></td>
<td>2SLS (2)</td>
</tr>
<tr>
<td></td>
<td>2SLS (3)</td>
</tr>
<tr>
<td>−1.12</td>
<td>−18.35**</td>
</tr>
<tr>
<td>(1.03)</td>
<td>(7.63)</td>
</tr>
<tr>
<td>−25.42**</td>
<td>(11.22)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>First-stage specification</th>
<th>Bins</th>
<th>Spline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local temperature</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Unit × hour × month FEs</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hour of sample FEs</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

| Observations | 4,820,775 | 4,820,775 | 4,820,775 |

Notes: Standard errors are two-way clustered by unit and date.

Reduction of local market capacity by 10% of mean market size
⇒ Markups increase by 120% of mean, 370% of mean marginal cost
Robustness checks

Local controls
- Add or remove local controls from estimation
- Estimates do not change

Minimum matching distance
- Match power plants to weather stations that are sufficiently far away
- Up to a distance of 300 km: estimates do not change

Effect of temperature on power plant operations
- Temperature may make power plants more costly to operate
- For a subset of units: estimate effect of matched temperature on operating efficiency
- Effects are small and not statistically significant
## Decomposition of effect

<table>
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<tr>
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<td>(1)</td>
</tr>
<tr>
<td>Local market capacity (GW)</td>
<td>−25.42**</td>
</tr>
<tr>
<td></td>
<td>(11.22)</td>
</tr>
<tr>
<td>Capacity owned by competing firms (GW)</td>
<td>−50.10**</td>
</tr>
<tr>
<td></td>
<td>(23.45)</td>
</tr>
<tr>
<td>Capacity owned by own firm (GW)</td>
<td>456.92*</td>
</tr>
<tr>
<td></td>
<td>(252.92)</td>
</tr>
<tr>
<td>Fossil fuel capacity (GW)</td>
<td>−27.59**</td>
</tr>
<tr>
<td></td>
<td>(12.15)</td>
</tr>
<tr>
<td>Non-fossil fuel capacity (GW)</td>
<td>−2.00</td>
</tr>
<tr>
<td></td>
<td>(73.96)</td>
</tr>
<tr>
<td>First-stage specification</td>
<td>Spline</td>
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<tr>
<td>Hour of sample FEs</td>
<td>X</td>
</tr>
<tr>
<td>Observations</td>
<td>4,820,775</td>
</tr>
</tbody>
</table>

**Notes:** Standard errors are two-way clustered by unit and date.
Welfare effects

Counterfactual: What price would result if firms did not exercise this form of market power?
- Consider temperatures greater than 30°C (86°F)
- Local markets are 1.1 GW smaller on average at these temperatures
- Average offer price is $27.1 per MWh higher at these temperatures
- In equilibrium, retail prices are $6.5 per MWh higher

Deadweight loss
- Long-run elasticity: -0.09 to -.27 (Deryugina, MacKay, & Reif 2017)
- $7.1–21.5 million annually

Transfers from consumers to producers
- $2.1 billion annually
Implications for climate change

Climate change $\Rightarrow$ 2.5°C temperature increase in 40–50 years
- Congestion becomes more common and more pervasive

Markups increase by $7.1$ per MWh (20% of marginal cost) on average

Welfare effects of climate change
- $9.4–27.8$ million of deadweight loss annually
- $2.5$ billion transfer from consumers to producers annually
Conclusions

Novel source of variation: transmission congestion
- Exogenous variation in market size, cross-sectionally and over time

Summary of results
- High temperatures: Local markets shrink by 12% and markups triple
- Causal effect: 10% reduction in market size $\Rightarrow$ Markups double
- Result driven by fossil fuel-fired capacity owned by competitors
- Own-firm capacity has large and opposite effect
- No response to non-fossil capacity (wind, nuclear, etc.)

Welfare effects
- Small deadweight loss but large transfers from consumers to producers
- Climate change will roughly double these effects
Thank you

Questions or comments?

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Prediction model of local market formation

Develop a prediction model of local market formation as a function of temperatures

- Match each power plant to the weather station that is most predictive of that plant’s local market size (Belloni et al. 2012)
- Representative of the prediction problem firms face in this setting

Predict local market size as a function of:

- Temperatures
- Hour-of-day by month-of-year indicators
- System-wide demand
- Lagged local market size (two-hour lag)
Distance from power plants to matched weather stations

![Graph showing the distance from power plants to matched weather stations. The x-axis represents distance in km, ranging from 0 to 800, and the y-axis represents the number of pairs, ranging from 0 to 200. The graph compares the number of closest weather stations to matched weather stations.](image-url)
Temperature-response for number of units in market

Temperature $> 40^\circ C (104^\circ F) \Rightarrow 10\%$ reduction from mean (152 units)
Temperature-response for number of firms in market

Temperature \( > 40^\circ C \ (104^\circ F) \Rightarrow 9\% \) reduction from mean (44 firms)
Temperature-response for market capacity without control

Temperature $> 40^\circ$C ($104^\circ$F) $\Rightarrow$ 16% reduction from mean (152 units)
Temperature-response for number of units without control

Temperature $> 40^\circ C \ (104^\circ F) \Rightarrow 13\% \ reduction \ from \ mean \ (152 \ units)$
Temperature-response for number of firms without control

Temperature > 40°C (104°F) ⇒ 11% reduction from mean (44 firms)
Temperature-response for markups at 75% capacity

Temperature $> 40^\circ$C ($104^\circ$F) $\Rightarrow$ 135% of mean markups at this quantity
Temperature-response for markups at 65% capacity

Temperature $> 40^\circ$C ($104^\circ$F) $\Rightarrow$ 165% of mean markups at this quantity
Temperature > 40°C (104°F) ⇒ 225% of mean markups at this quantity
Temperature-response for markups at 75% without control

Temperature > 40°C (104°F) ⇒ 150% of mean markups at this quantity
Temperature-response for markups at 65% without control

Temperature $> 40^\circ$C ($104^\circ$F) $\Rightarrow$ 170% of mean markups at this quantity
## Effect of number of units on markups

<table>
<thead>
<tr>
<th>First-stage specification</th>
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<th>Spline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units in local market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(−0.18, −5.74**, −10.27**)</td>
<td>(0.37, 2.79, 5.06)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>4,820,775</td>
<td>4,820,775</td>
</tr>
</tbody>
</table>

*Notes: Standard errors are two-way clustered by unit and date.*

Reduction in number of units by 10% of mean market size
⇒ Markups increase by 140% of mean, 425% of mean marginal cost
### Effect of number of firms on markups

<table>
<thead>
<tr>
<th></th>
<th>Markup at 85% capacity ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS (1)</td>
</tr>
<tr>
<td>Firms in local market</td>
<td>$-0.85$</td>
</tr>
<tr>
<td></td>
<td>(1.33)</td>
</tr>
<tr>
<td></td>
<td>2SLS (2)</td>
</tr>
<tr>
<td></td>
<td>$-23.82^{**}$</td>
</tr>
<tr>
<td></td>
<td>(10.64)</td>
</tr>
<tr>
<td></td>
<td>2SLS (3)</td>
</tr>
<tr>
<td></td>
<td>$-41.10^{**}$</td>
</tr>
<tr>
<td></td>
<td>(19.17)</td>
</tr>
</tbody>
</table>

**First-stage specification**

- **Bins**: X
- **Spline**: X

**Local temperature**: X

**Unit × hour × month FEs**: X

**Hour of sample FEs**: X

**Observations**: 4,820,775 4,820,775 4,820,775

**Notes**: Standard errors are two-way clustered by unit and date.

Reduction in number of firms by 10% of mean market size

⇒ Markups increase by 160% of mean, 490% of mean marginal cost
### Effect of market size on markups at 75% capacity

<table>
<thead>
<tr>
<th>Markup at 75% capacity ($/MWh)</th>
<th>OLS (1)</th>
<th>2SLS (2)</th>
<th>2SLS (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local market capacity (GW)</td>
<td>−0.99</td>
<td>−11.98**</td>
<td>−15.24**</td>
</tr>
<tr>
<td></td>
<td>(0.99)</td>
<td>(5.36)</td>
<td>(6.46)</td>
</tr>
</tbody>
</table>

First-stage specification

- Bins
- Spline

Local temperature

- X
- X

Unit × hour × month FEs

- X
- X
- X

Hour of sample FEs

- X
- X
- X

Observations

- 5,224,152
- 5,224,152
- 5,224,152

**Notes:** Standard errors are two-way clustered by unit and date.

Reduction of local market capacity by 10% of mean market size

⇒ Markups increase by 75% of mean, 220% of mean marginal cost
Effect of market size on markups at 65% capacity

<table>
<thead>
<tr>
<th>Local market capacity (GW)</th>
<th>OLS (1)</th>
<th>2SLS (2)</th>
<th>2SLS (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>−0.74</td>
<td>−9.64***</td>
<td>−13.00***</td>
</tr>
<tr>
<td></td>
<td>(0.80)</td>
<td>(3.05)</td>
<td>(5.03)</td>
</tr>
</tbody>
</table>

First-stage specification

<table>
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<th>Local temperature</th>
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<td>Unit × hour × month FEs</td>
<td>X</td>
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<td>Hour of sample FEs</td>
<td>X</td>
<td>X</td>
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Observations 5,415,331 5,415,331 5,415,331

Notes: Standard errors are two-way clustered by unit and date.

Reduction of local market capacity by 10% of mean market size
⇒ Markups increase by 95% of mean, 190% of mean marginal cost

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## Robustness to local controls

<table>
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<tr>
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<th>Markup at 85% capacity ($/MWh)</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Local market capacity (GW)</td>
<td>$-25.42^{**}$</td>
<td>$-20.69^{**}$</td>
<td>$-23.70^{**}$</td>
<td>$-29.80^{**}$</td>
</tr>
<tr>
<td></td>
<td>(11.22)</td>
<td>(8.30)</td>
<td>(9.68)</td>
<td>(14.10)</td>
</tr>
<tr>
<td>Local temperature</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Local capacity factor</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Unit $\times$ month $\times$ hour FEs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Hour of sample FEs</td>
<td>X</td>
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Notes: Standard errors are two-way clustered by unit and date.
**Robustness to minimum matching distance**

<table>
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<tr>
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<td></td>
<td>−25.42**</td>
</tr>
<tr>
<td></td>
<td>(11.22)</td>
</tr>
<tr>
<td>Minimum matching distance (km)</td>
<td>0</td>
</tr>
<tr>
<td>Local temperature</td>
<td>X</td>
</tr>
<tr>
<td>Unit × month × hour FEs</td>
<td>X</td>
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*Notes:* Standard errors are two-way clustered by unit and date.
Robustness of power plant operations

Typical range of heat rates for fossil fuel-fired units: 7–14 MMBtu/MWh