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

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# Market power

Consequences of market power

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

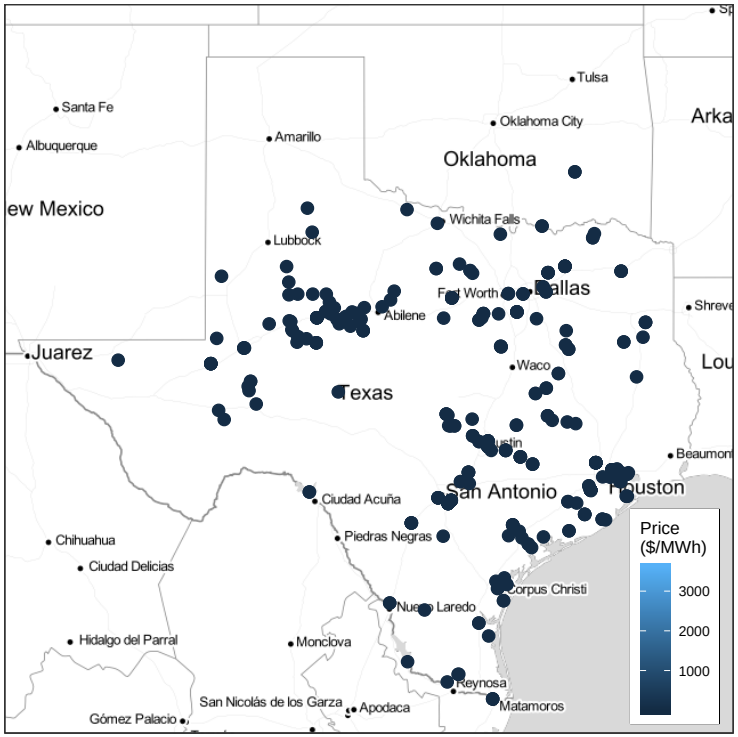
Economic theory: market structure is primary factor in market power

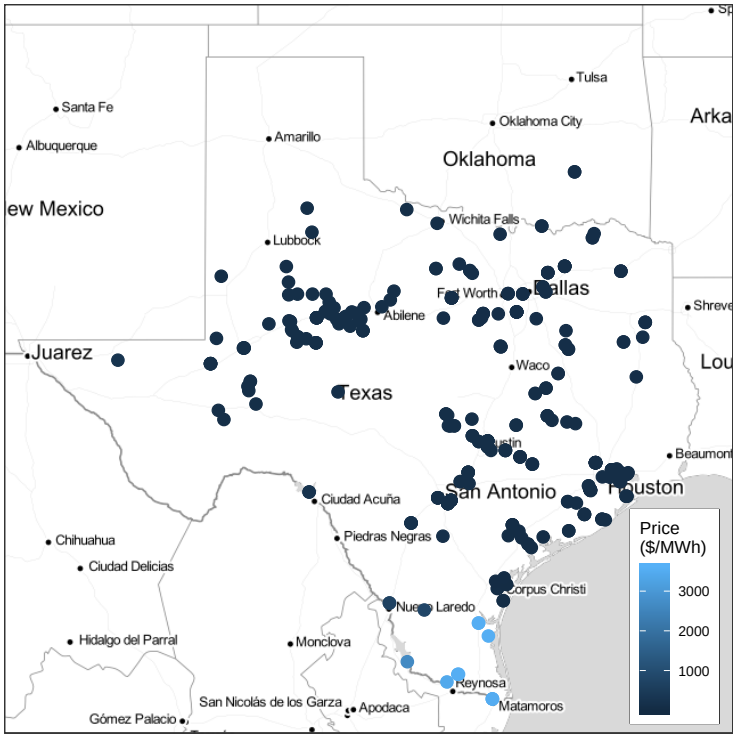
- Market structure and market power are equilibrium outcomes
- Causal effect is challenging to estimate
- Identification typically requires assumptions on behavior or competition

# 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)

$\Rightarrow$ 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)

$\Rightarrow$ 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

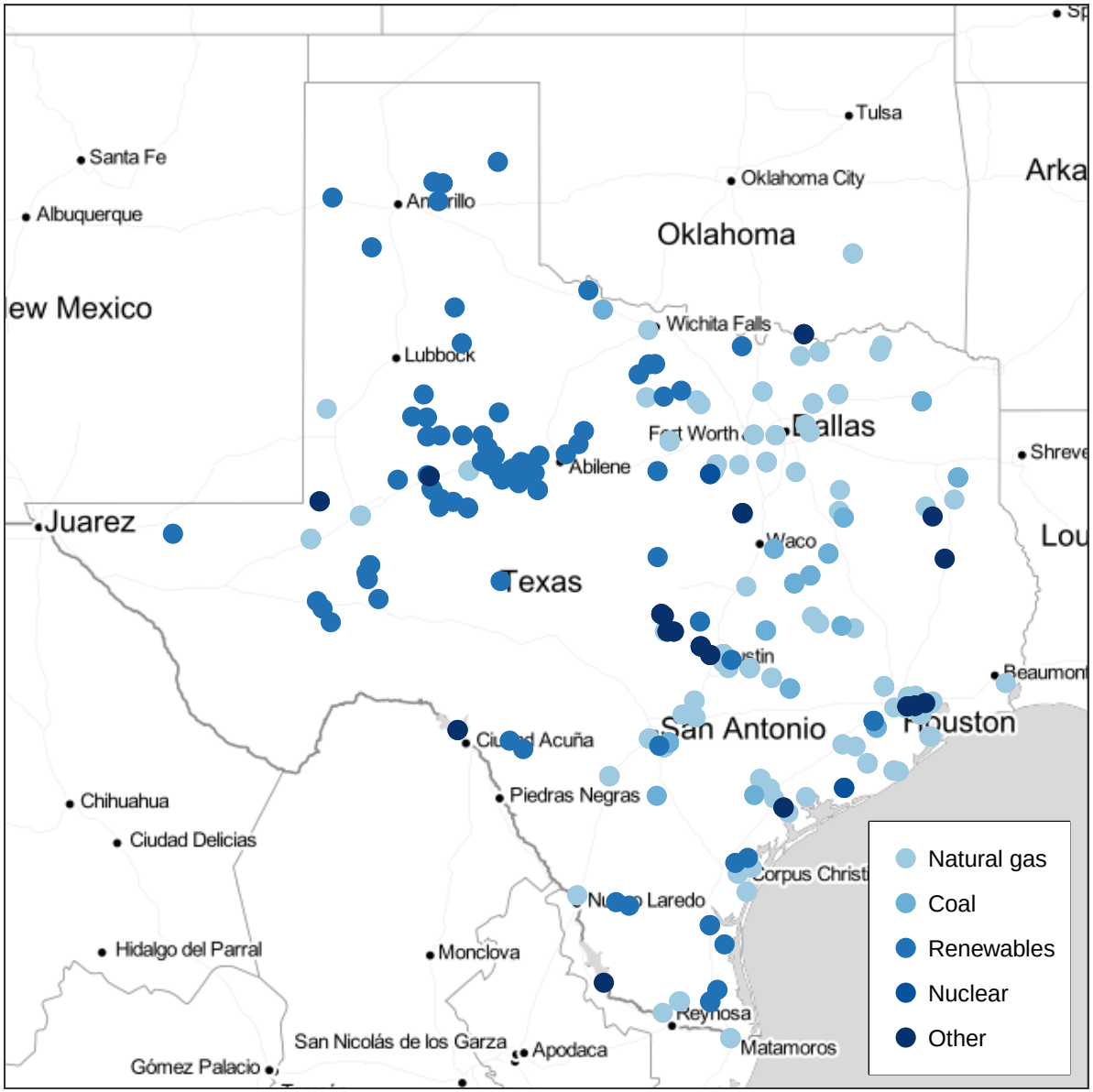
ERCOT (Electricity Reliability Council of Texas)

- 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

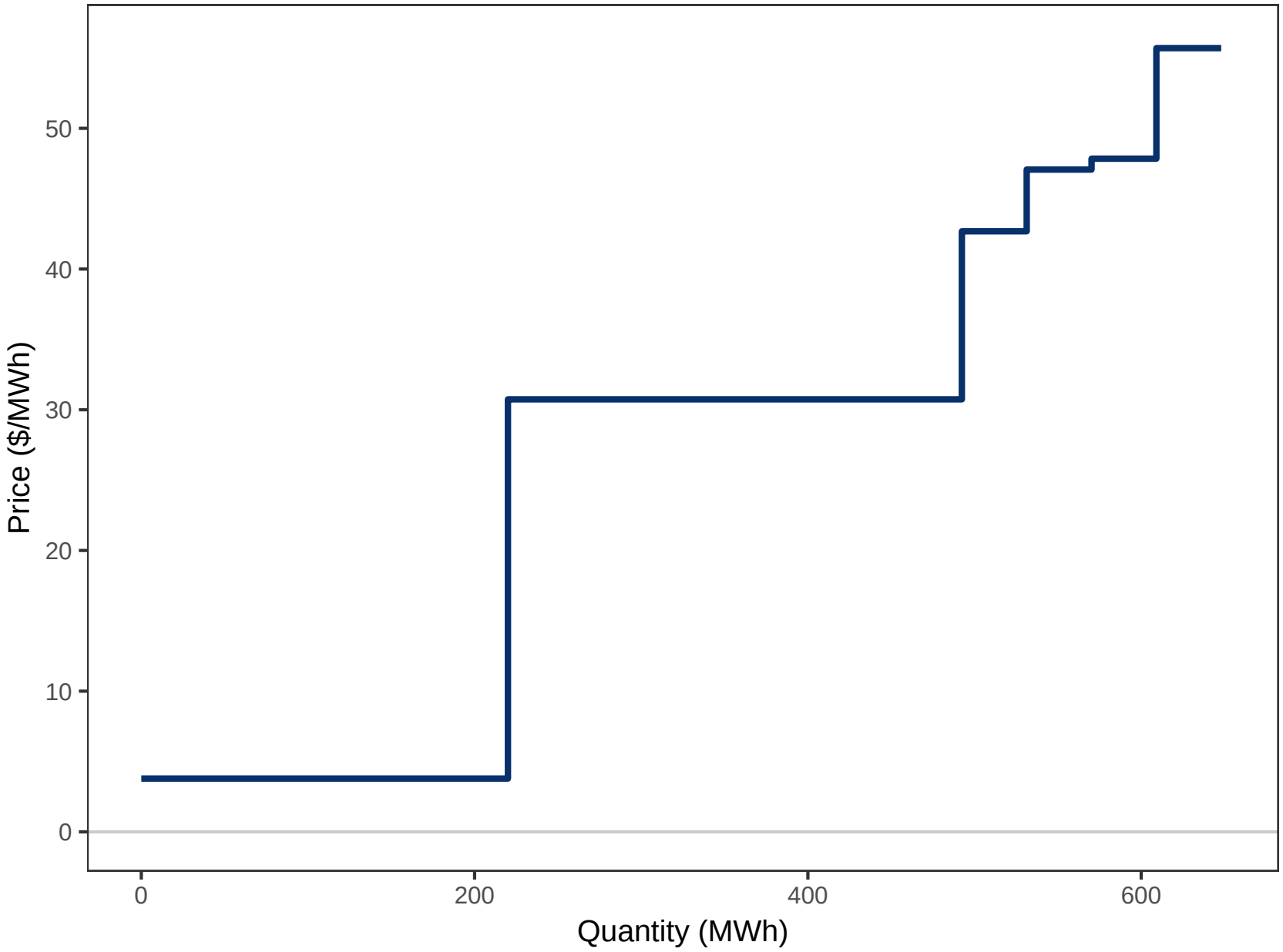
Real-time wholesale electricity market

- 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

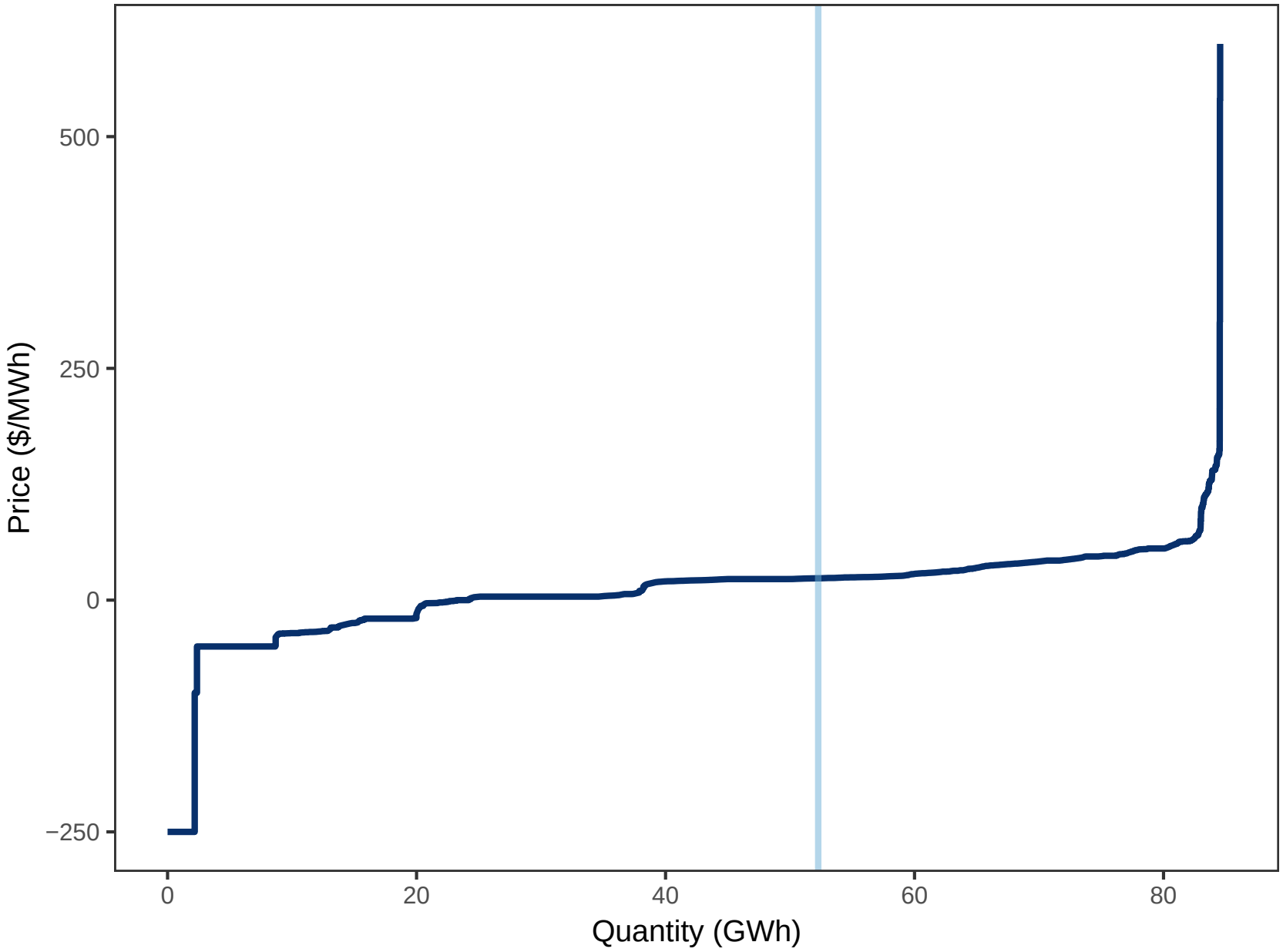
# Power plants in the Texas electricity market



# Offer curve



# Market offer curve



# 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

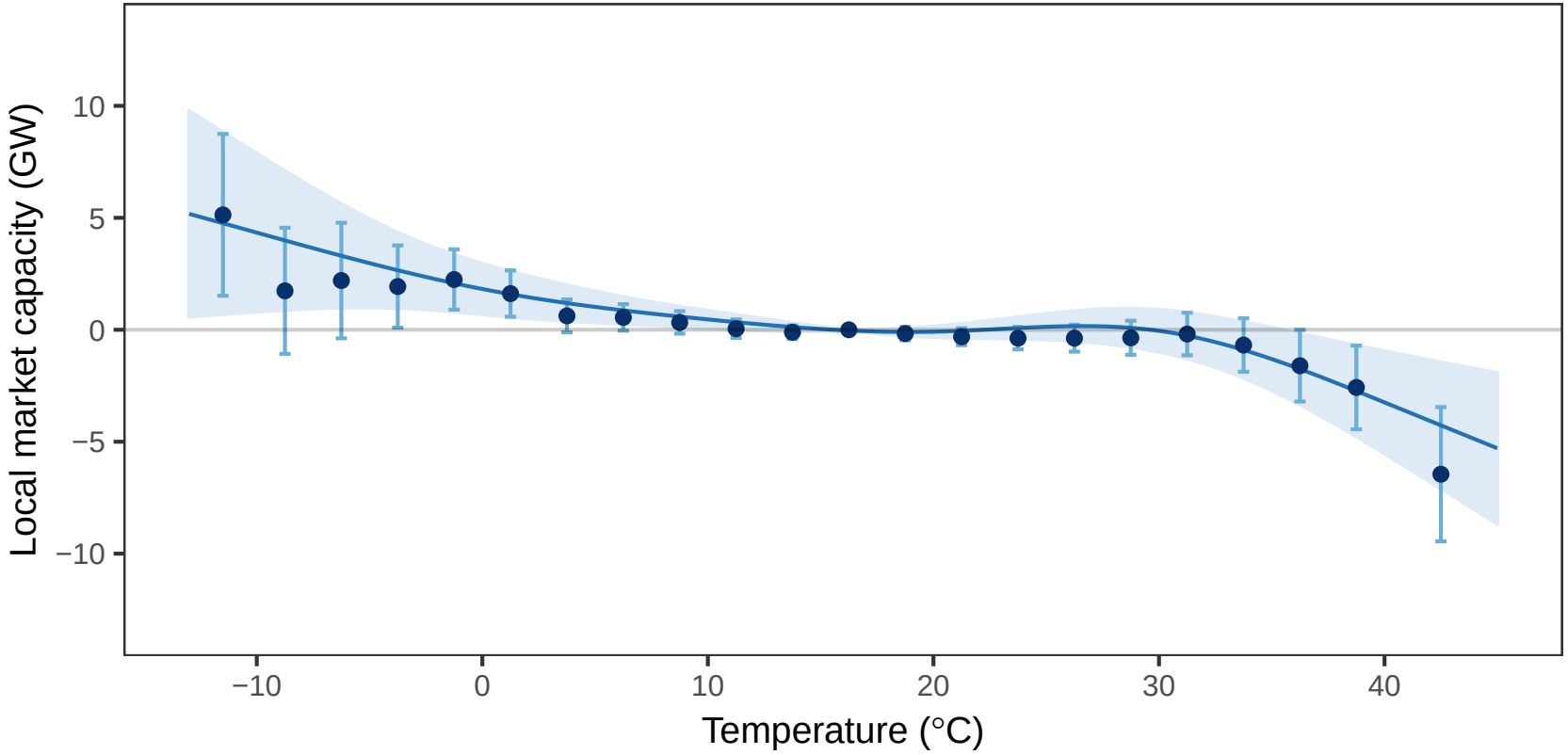
$$Markup_{it} = \beta \widehat{Size}_{it} + g(LocalTemp_{it}) + \gamma_{ihm} + \delta_t + \varepsilon_{it}$$
$$Size_{it} = f(MatchedTemp_{it}) + g(LocalTemp_{it}) + \eta_{ihm} + \theta_t + \omega_{it}$$

- 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

$$\text{Cov}(MatchedTemp_{it}, Size_{it} \mid LocalTemp_{it}, \eta_{ihm}, \theta_t) \neq 0$$
$$\text{Cov}(MatchedTemp_{it}, \varepsilon_{it} \mid LocalTemp_{it}, \gamma_{ihm}, \delta_t) = 0$$

# Temperature-response of market size

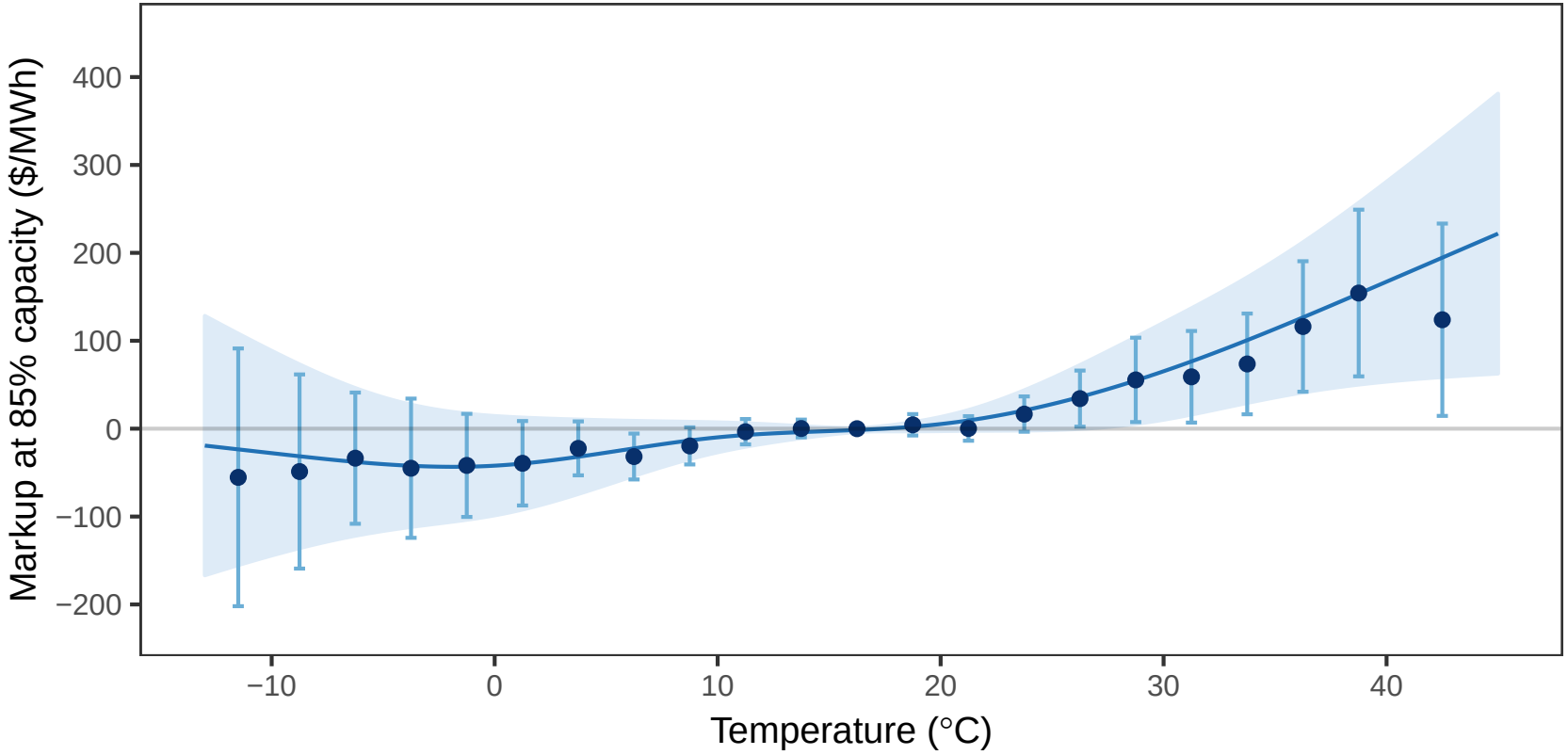



Temperature $> 40°$C (104°F) $\Rightarrow$ 12% reduction from mean (53 GW)

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

▸ Units and firms ▸ Without control

# Temperature-response of markups




Temperature $>$ 40°C (104°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

| | Markup at 85% capacity ($/MWh) | | |
|---|---|---|---|
| | OLS (1) | 2SLS (2) | 2SLS (3) |
| Local market capacity (GW) | −1.12 | −18.35** | −25.42** |
| | (1.03) | (7.63) | (11.22) |
| First-stage specification | | Bins | Spline |
| Local temperature | | X | X |
| Unit × hour × month FEs | X | X | X |
| Hour of sample FEs | X | X | X |
| 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

▸ Units ▸ Firms ▸ 75% ▸ 65%

# Robustness checks

Local controls ▸ Table

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

Minimum matching distance ▸ Table

- 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 ▸ Figure

- 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

| | Markup at 85% capacity ($/MWh) | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Local market capacity (GW) | −25.42** | | |
| | (11.22) | | |
| Capacity owned by competing firms (GW) | | −50.10** | |
| | | (23.45) | |
| Capacity owned by own firm (GW) | | 456.92* | |
| | | (252.92) | |
| Fossil fuel capacity (GW) | | | −27.59** |
| | | | (12.15) |
| Non-fossil fuel capacity (GW) | | | −2.00 |
| | | | (73.96) |
| First-stage specification | Spline | Spline | Spline |
| Local temperature | X | X | X |
| Unit × hour × month FEs | X | X | X |
| Hour of sample FEs | X | X | X |
| Observations | 4,820,775 | 4,820,775 | 4,820,775 |

*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

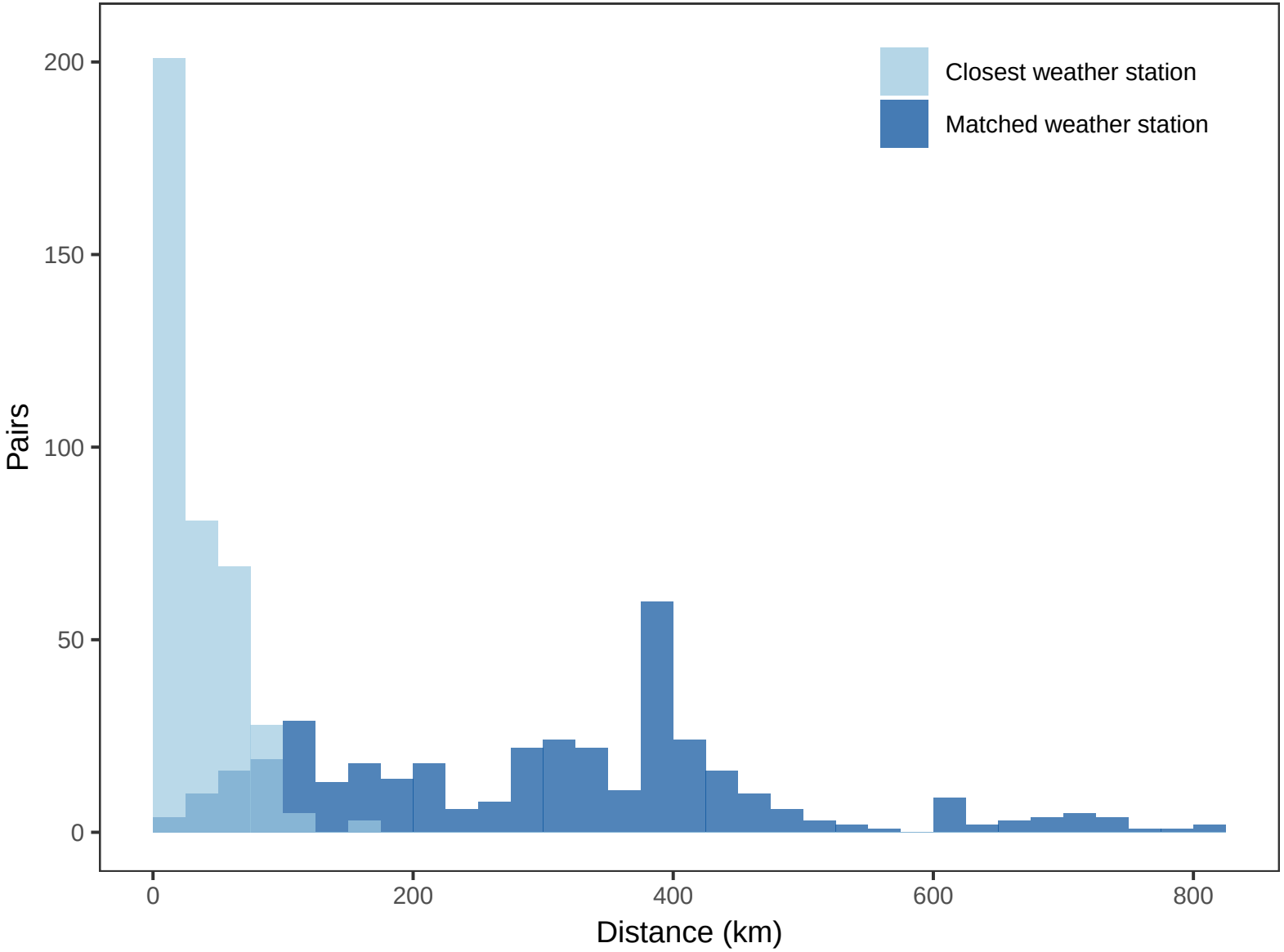
Develop a prediction model of local market formation as a function of temperatures

- 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

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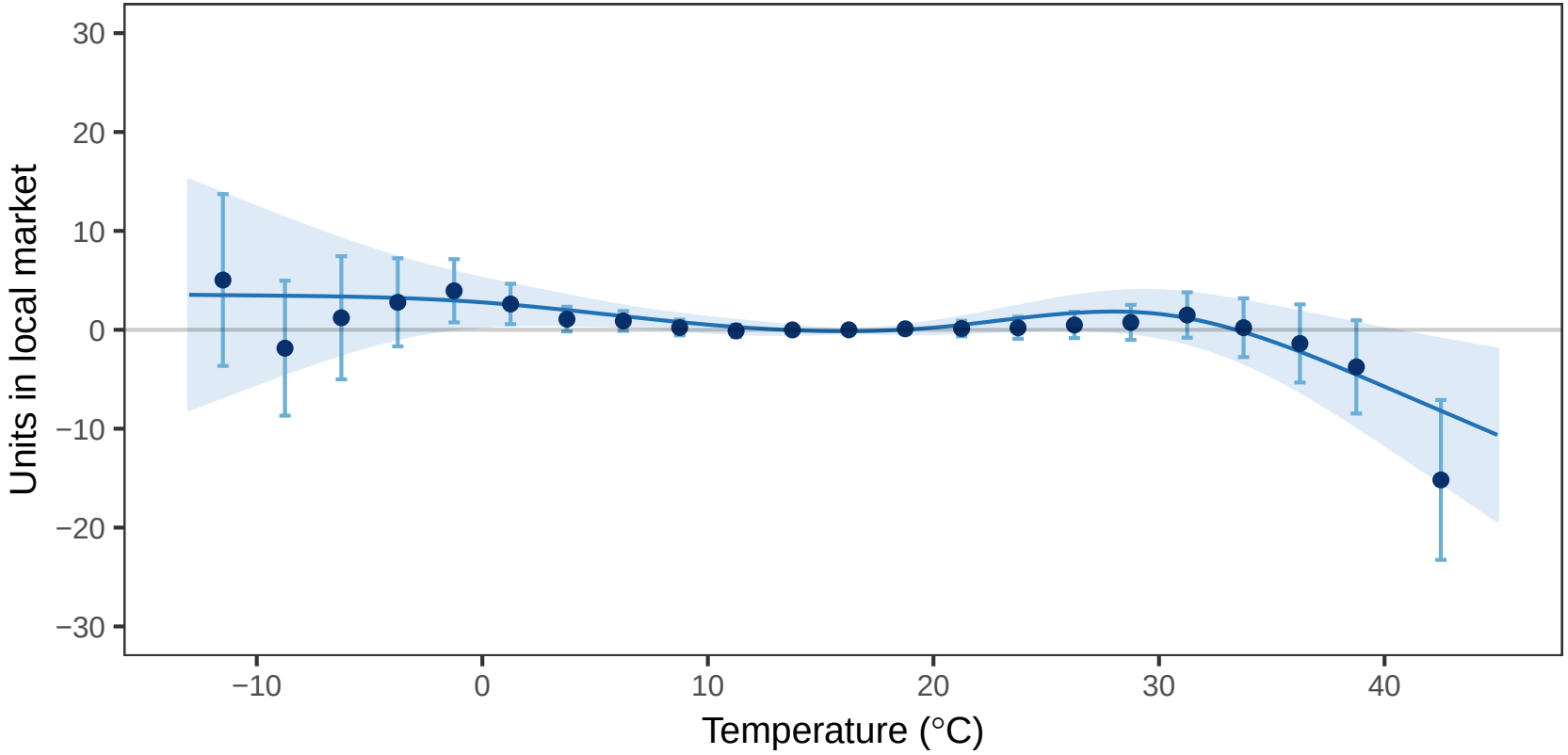
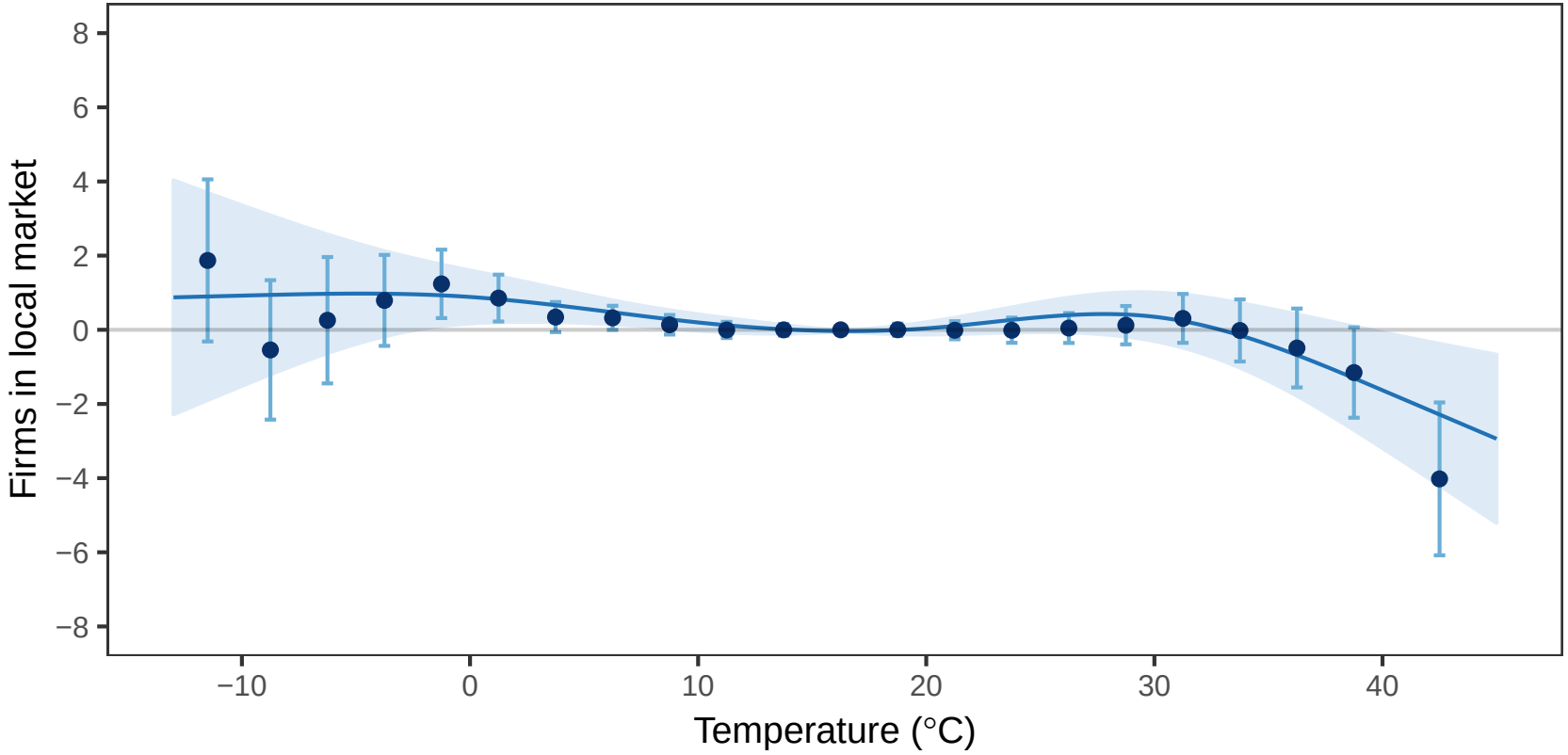
# Temperature-response for number of units in market




Temperature $> 40°$C (104°F) $\Rightarrow$ 10% reduction from mean (152 units)

# Temperature-response for number of firms in market




Temperature $> 40°$C (104°F) $\Rightarrow$ 9% reduction from mean (44 firms)

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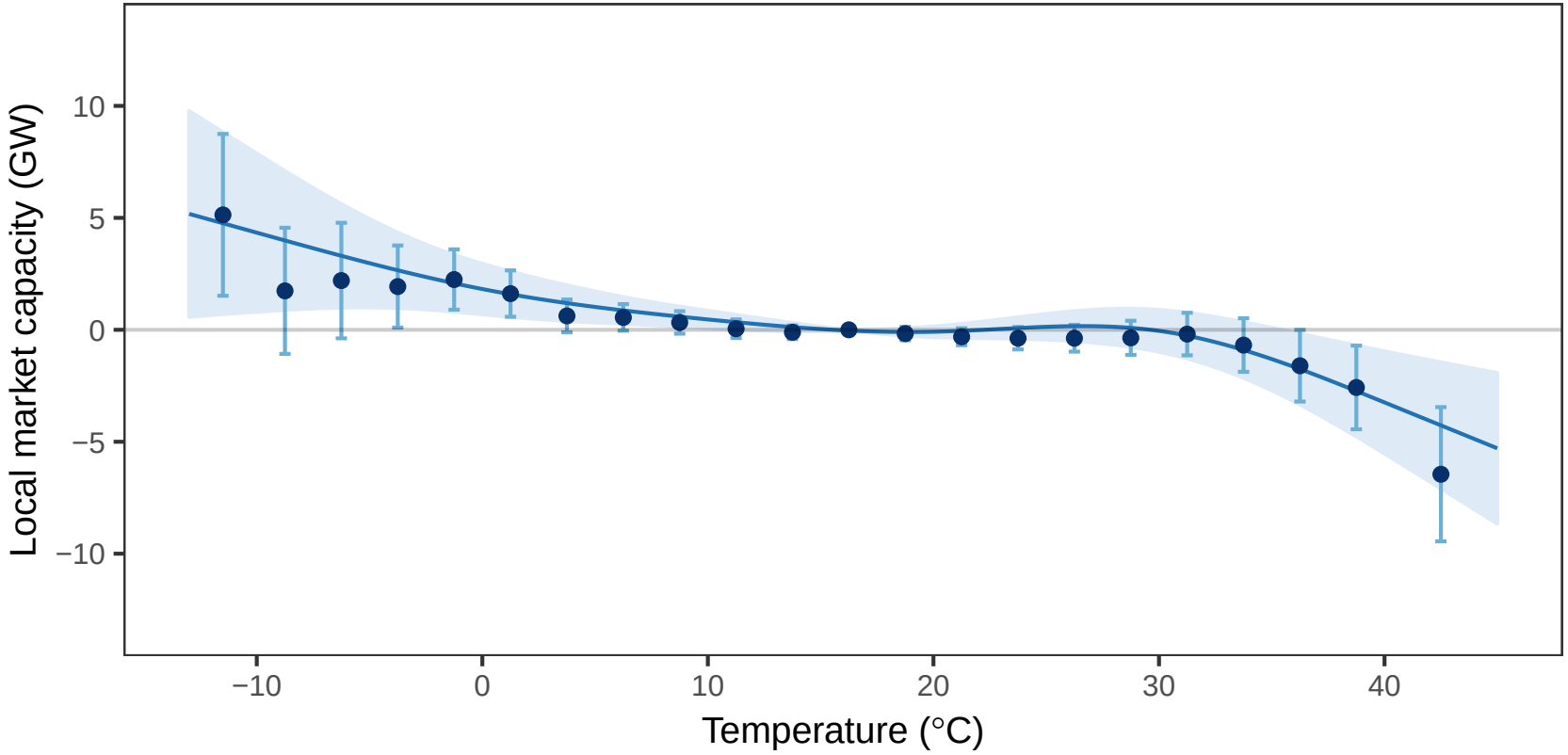
# Temperature-response for market capacity without control




Temperature $> 40°$C (104°F) $\Rightarrow$ 16% reduction from mean (152 units)

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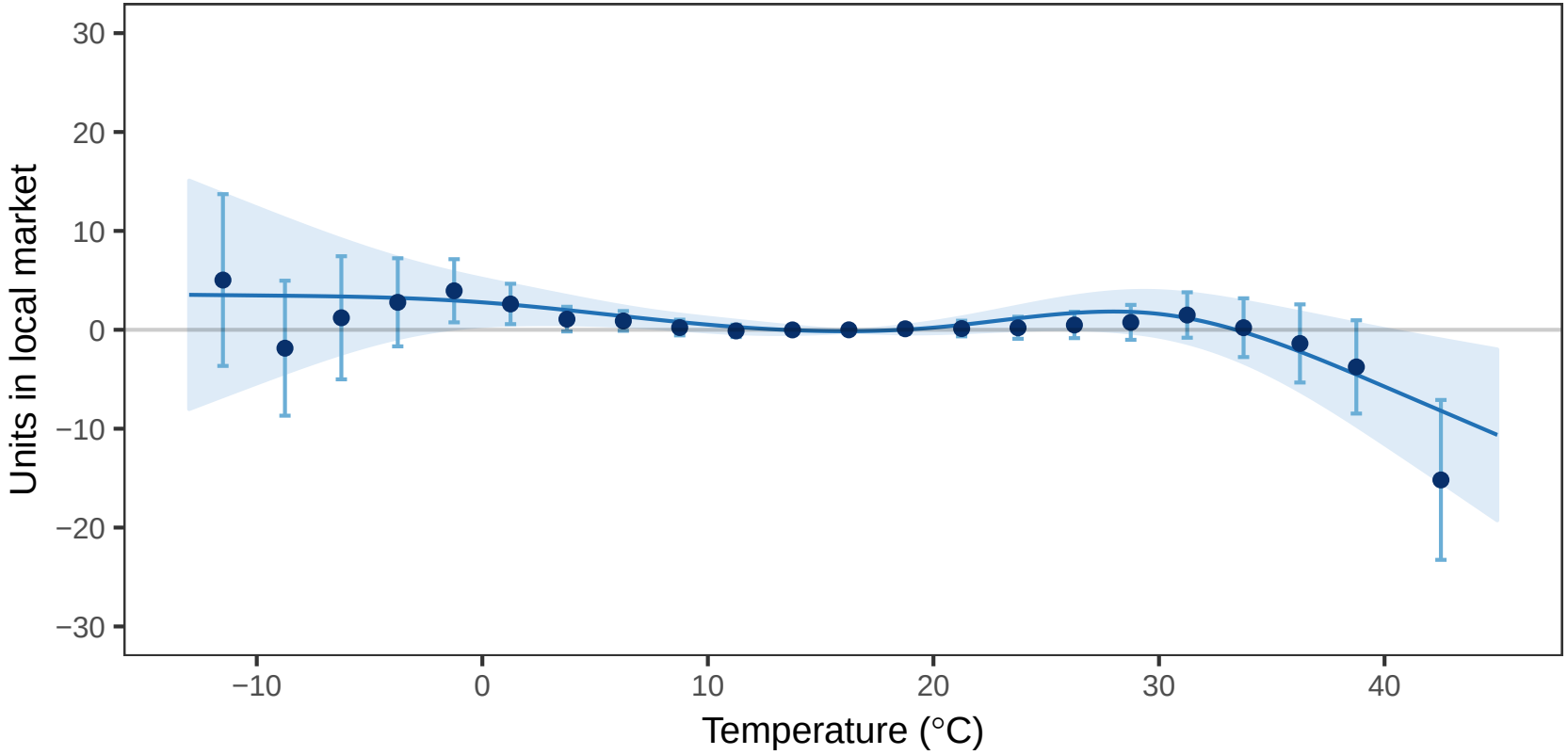
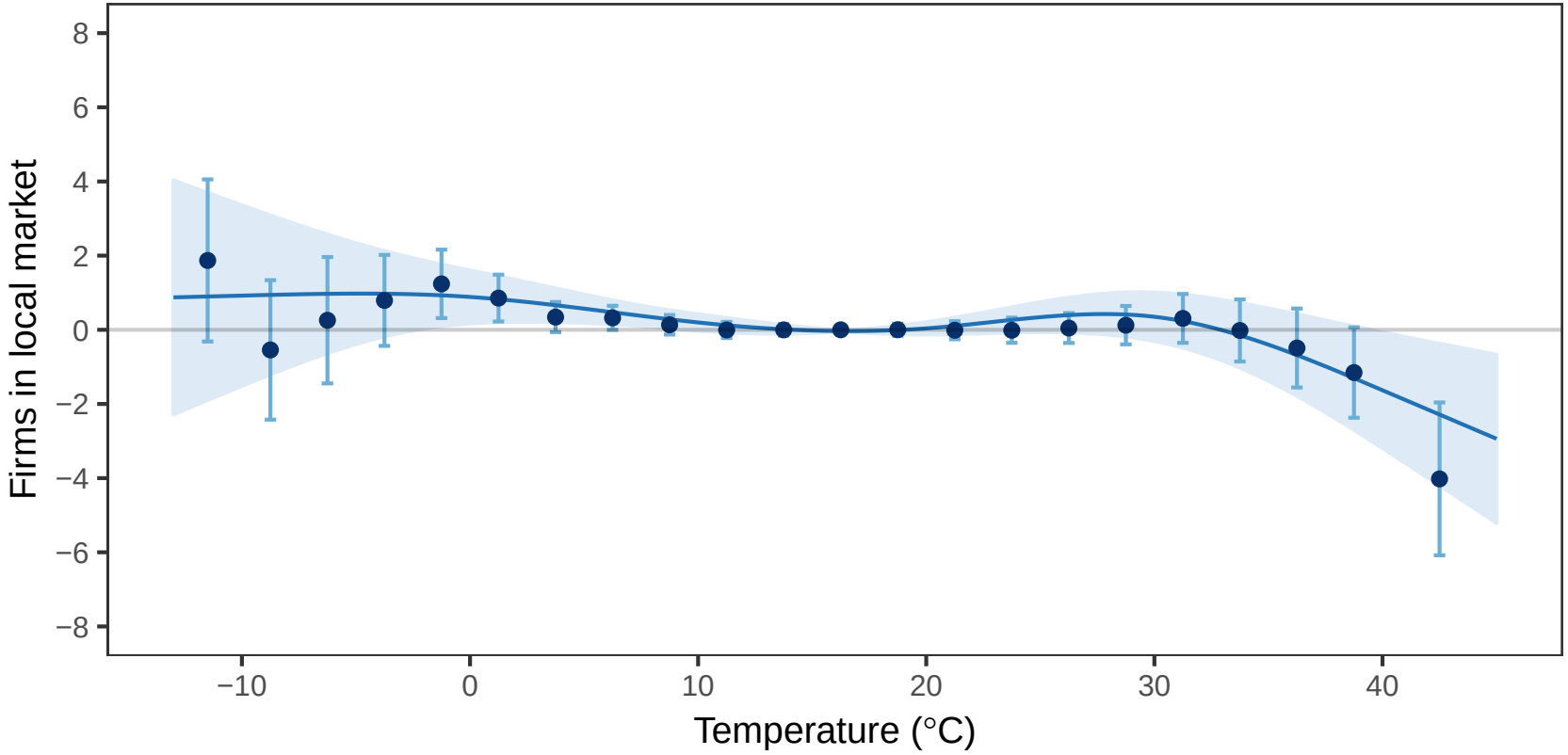
# Temperature-response for number of units without control




Temperature $> 40°$C (104°F) $\Rightarrow$ 13% reduction from mean (152 units)

# Temperature-response for number of firms without control




Temperature $> 40°$C (104°F) $\Rightarrow$ 11% reduction from mean (44 firms)

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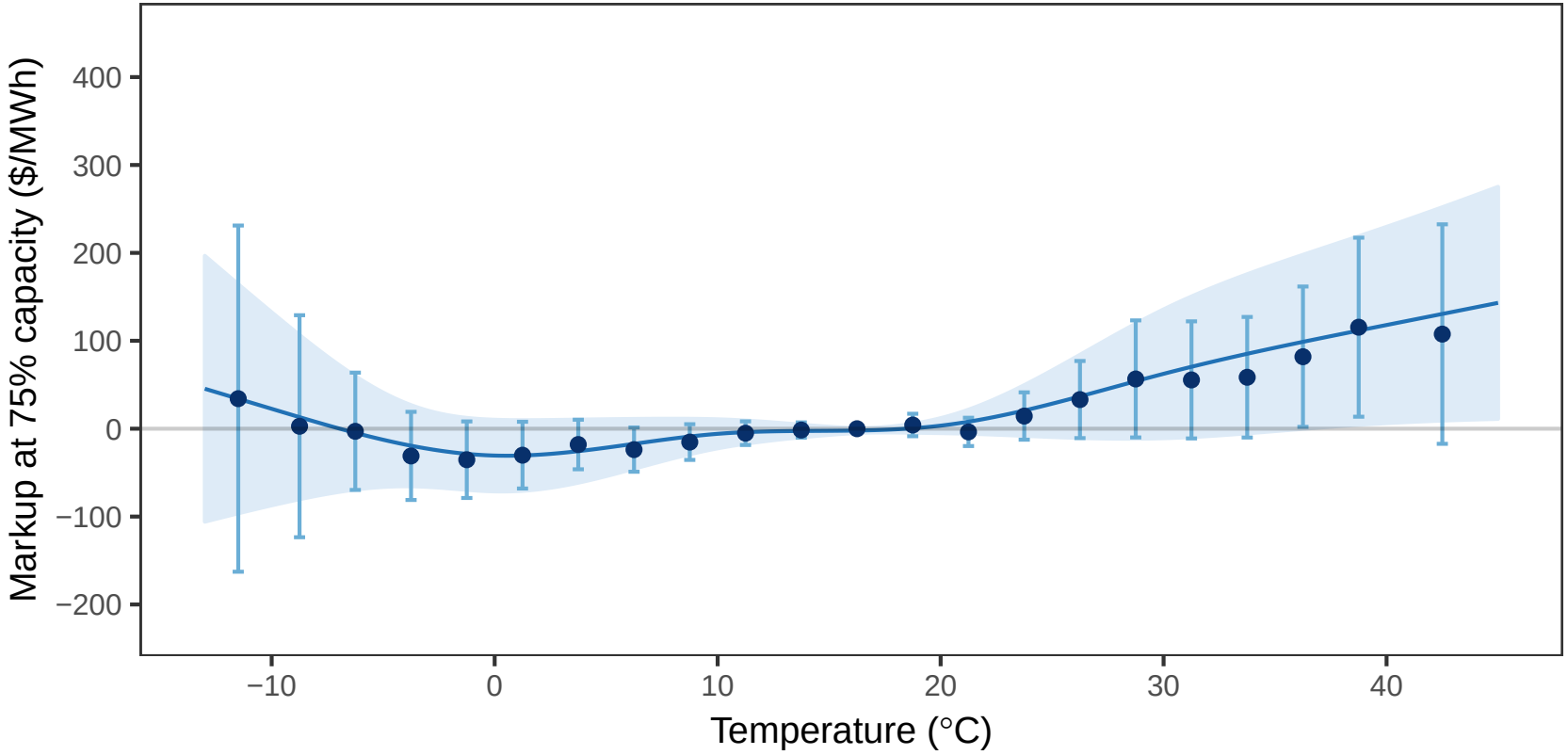
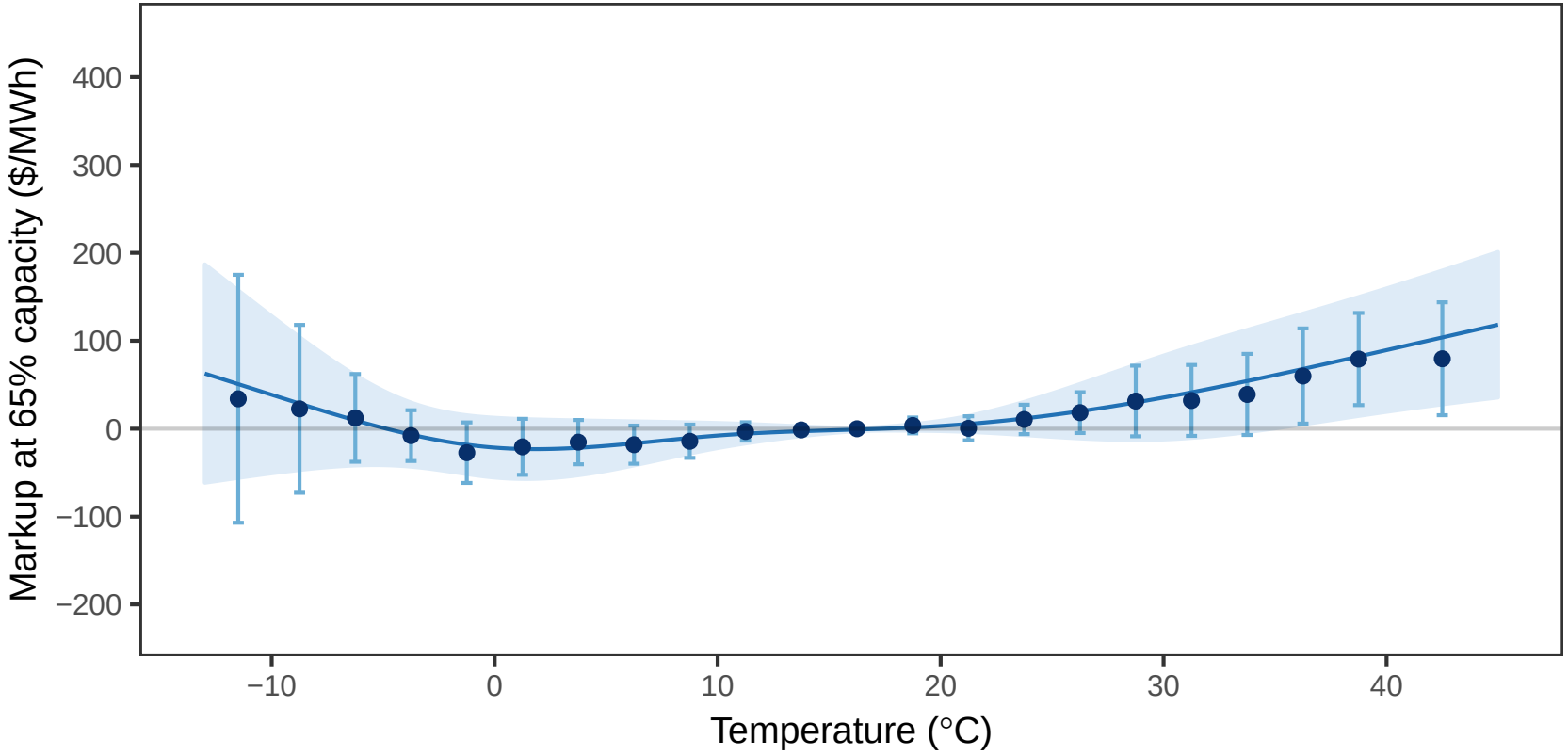
# Temperature-response for markups at 75% capacity




Temperature $> 40°$C (104°F) $\Rightarrow$ 135% of mean markups at this quantity

# Temperature-response for markups at 65% capacity




Temperature $> 40°$C (104°F) $\Rightarrow$ 165% of mean markups at this quantity

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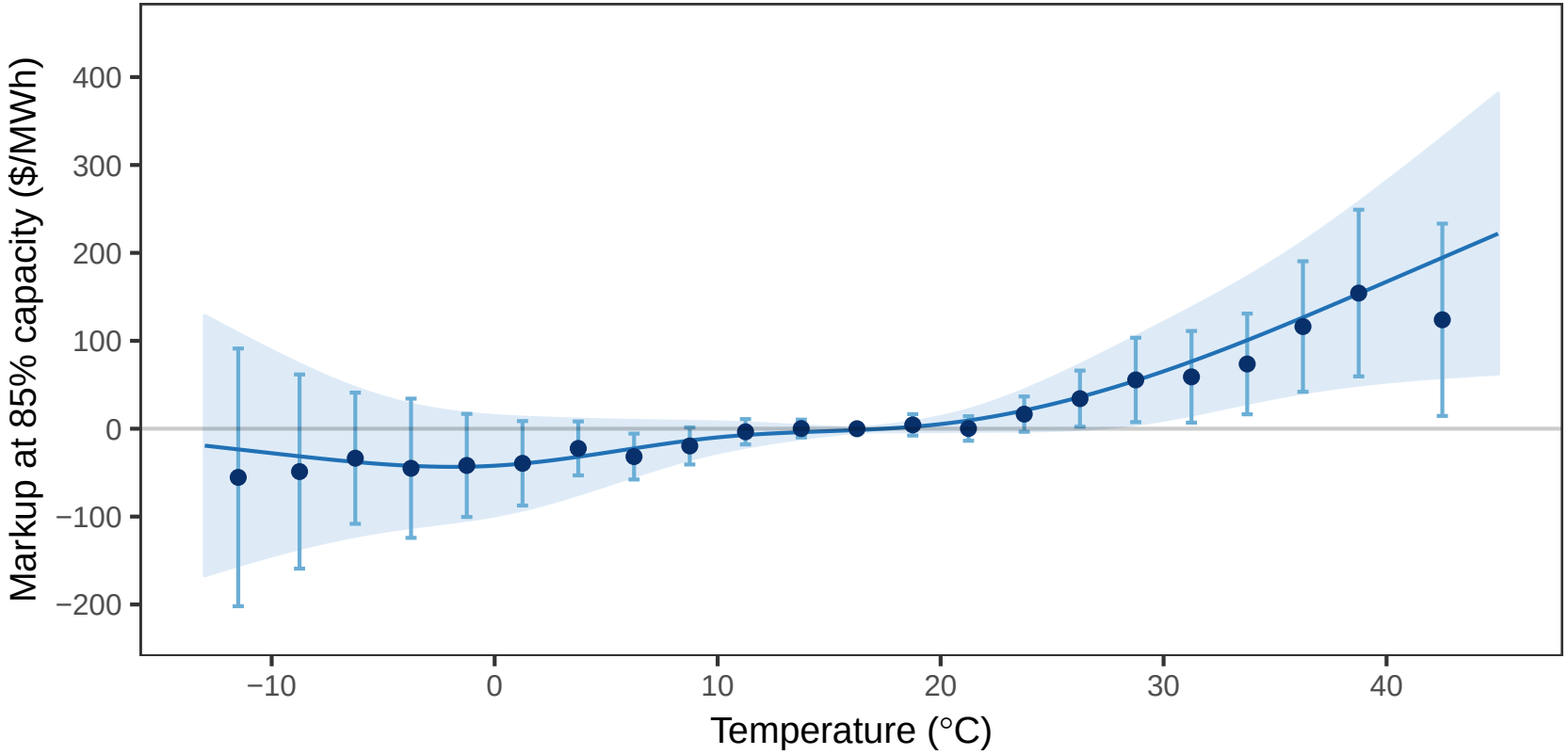
# Temperature-response for markups at 85% without control




Temperature $> 40°C$ (104°F) $\Rightarrow$ 225% of mean markups at this quantity

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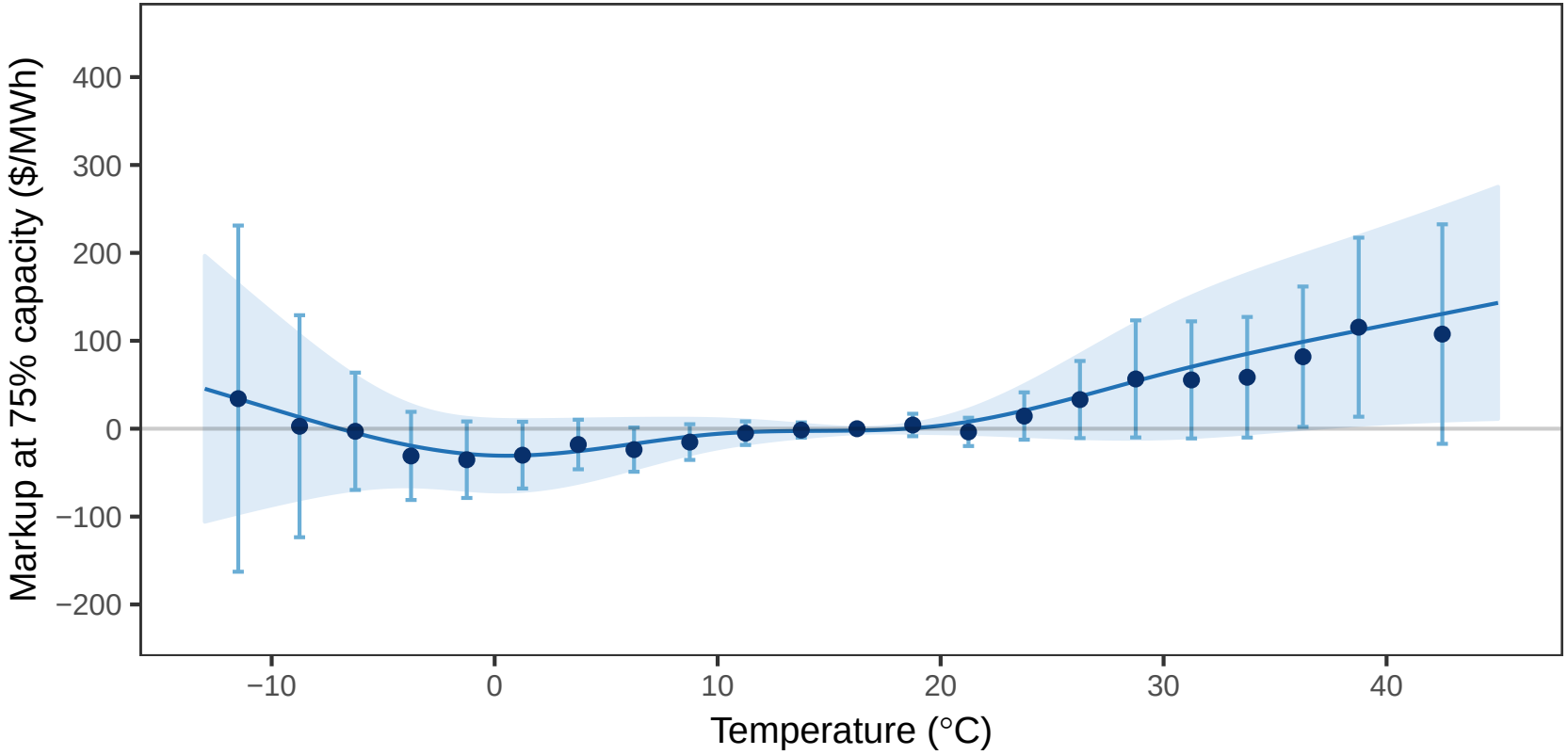
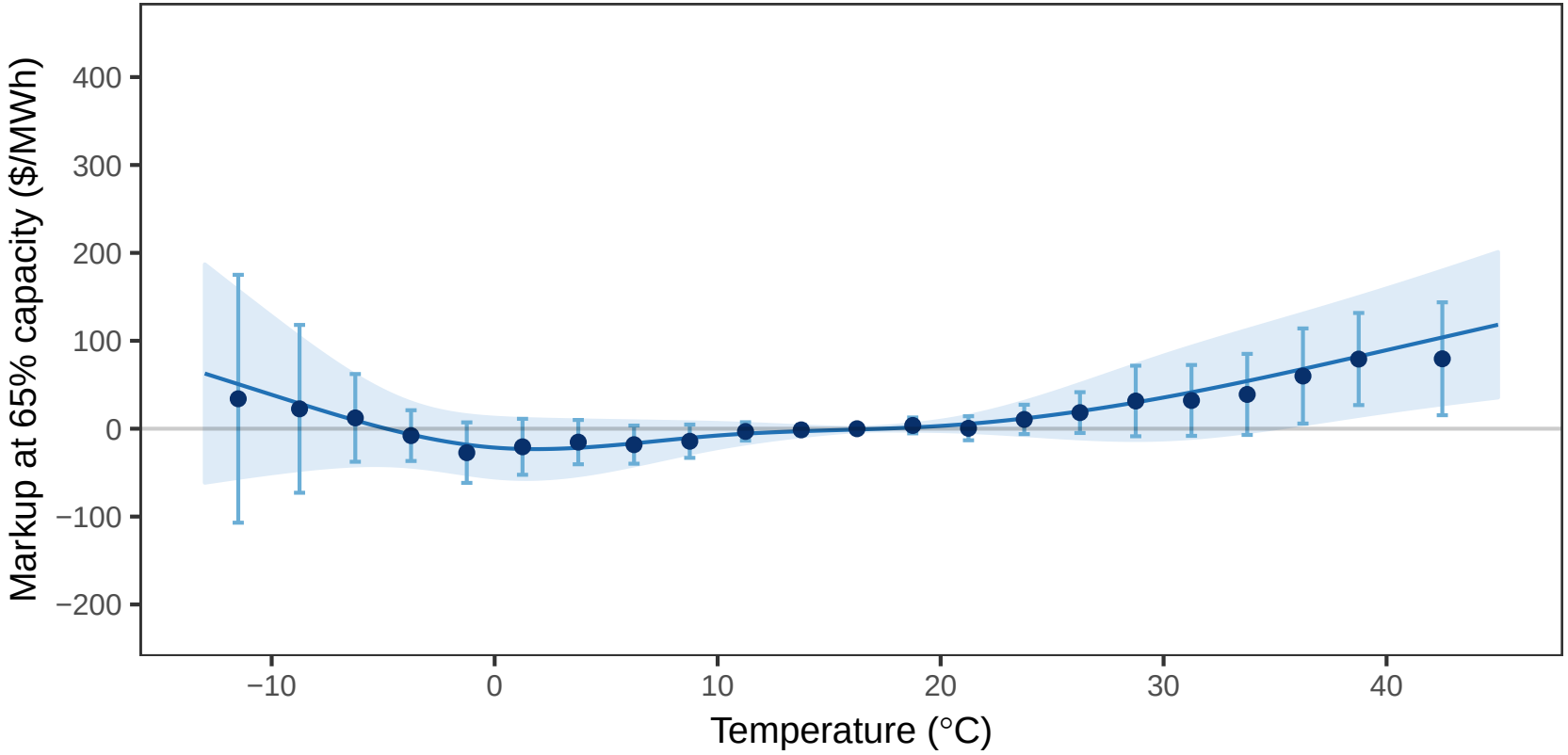
# Temperature-response for markups at 75% without control




Temperature $> 40°$C (104°F) $\Rightarrow$ 150% of mean markups at this quantity

# Temperature-response for markups at 65% without control




Temperature $> 40°$C (104°F) $\Rightarrow$ 170% of mean markups at this quantity

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# Effect of number of units on markups

| | Markup at 85% capacity ($/MWh) | | |
|---|---|---|---|
| | OLS (1) | 2SLS (2) | 2SLS (3) |
| Units in local market | −0.18 | −5.74** | −10.27** |
| | (0.37) | (2.79) | (5.06) |
| First-stage specification | | Bins | Spline |
| Local temperature | | X | X |
| Unit × hour × month FEs | X | X | X |
| Hour of sample FEs | X | X | 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 units by 10% of mean market size
⇒ Markups increase by 140% of mean, 425% of mean marginal cost

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# Effect of number of firms on markups

| | Markup at 85% capacity ($/MWh) | | |
|---|---|---|---|
| | OLS (1) | 2SLS (2) | 2SLS (3) |
| Firms in local market | −0.85 | −23.82** | −41.10** |
| | (1.33) | (10.64) | (19.17) |
| First-stage specification | | Bins | Spline |
| Local temperature | | X | X |
| Unit × hour × month FEs | X | X | X |
| Hour of sample FEs | X | X | 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

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# Effect of market size on markups at 75% capacity

| | Markup at 75% capacity ($/MWh) | | |
|---|---|---|---|
| | OLS (1) | 2SLS (2) | 2SLS (3) |
| Local market capacity (GW) | −0.99 | −11.98** | −15.24** |
| | (0.99) | (5.36) | (6.46) |
| 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

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# Effect of market size on markups at 65% capacity

| | Markup at 65% capacity ($/MWh) | | |
|---|---|---|---|
| | OLS (1) | 2SLS (2) | 2SLS (3) |
| Local market capacity (GW) | −0.74 | −9.64*** | −13.00*** |
| | (0.80) | (3.05) | (5.03) |
| First-stage specification | | Bins | Spline |
| Local temperature | | X | X |
| Unit × hour × month FEs | X | X | X |
| Hour of sample FEs | X | X | X |
| Observations | 5,415,331 | 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

| | Markup at 85% capacity ($/MWh) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Local market capacity (GW) | $-25.42^{**}$ | $-20.69^{**}$ | $-23.70^{**}$ | $-29.80^{**}$ |
| | (11.22) | (8.30) | (9.68) | (14.10) |
| Local temperature | X | | | X |
| Local capacity factor | | | X | X |
| Unit × month × hour FEs | X | X | X | X |
| Hour of sample FEs | X | X | X | X |
| Observations | 4,820,775 | 4,820,775 | 4,820,775 | 4,820,775 |

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

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# Robustness to minimum matching distance

| | Markup at 85% capacity ($/MWh) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Local market capacity (GW) | −25.42** | −28.33*** | −33.53** | −18.89** |
| | (11.22) | (10.99) | (13.27) | (9.11) |
| Minimum matching distance (km) | 0 | 100 | 200 | 300 |
| Local temperature | X | | | |
| Unit × month × hour FEs | X | X | X | X |
| Hour of sample FEs | X | X | X | X |
| Observations | 4,820,775 | 4,820,775 | 4,820,775 | 4,820,775 |

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

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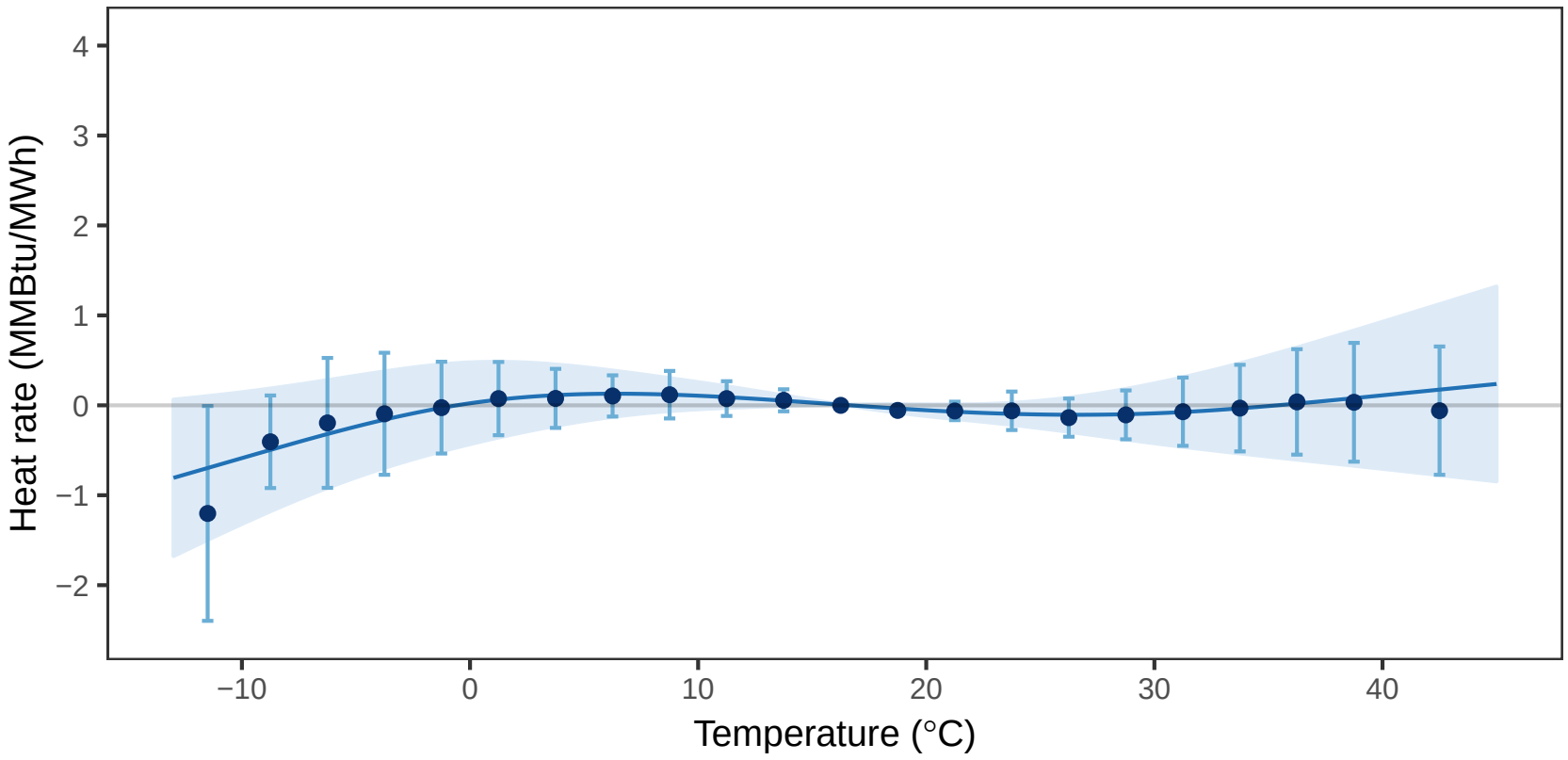
# Robustness of power plant operations




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

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