Heterogeneous Impacts of Cost Shocks, Strategic Bidding and Pass-Through: Evidence from the New England Electricity Market

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New England Electricity Market: Reliance on Natural Gas

New England Electricity Generation’s reliance on Natural Gas has increased substantially.
Pipeline Constraints in New England

- Gas flows into NE from south via Algonquin Gas Transmission and Tennessee Gas Pipeline
- Because of the Gas pipeline constraints, NG prices at citygates in NE is higher than in other places
Gas spot price shocks in the winters of 2013 and 2014

Severe Gas Pipeline Congestions
- In winters of 2013 and 2014, these pipelines were operating at near or full capacity almost every day → Severe Pipeline Congestion
  - Record cold weather swept Northeast

Gas Spot Price Shocks in New England
- Congestion reflected in NG spot price → Gas Spot Price shock (at city gates in New England)
- Gas price shock = Input cost shock to electricity generators → Led to spikes in Electricity Prices
Gas spot price shocks and the wholesale electricity prices in the winters of 2013 and 2014

Policy relevant question to ask...

“How much of the input gas cost shock was passed onto the electricity prices?”

→ Cost Pass-through
Gas spot price shocks and the wholesale electricity prices in the winters of 2013 and 2014

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→ Cost Pass-through
Research Question

- Interesting feature of the gas price shock: **Heterogeneity** of the shock’s impact on electricity generation costs → the extent of cost increase differ across firms

- Focusing on this cost impact heterogeneity, I study:

  “Implications of cost impact heterogeneity on the market competition and the subsequent pass-through of cost shocks”
Interesting feature of the gas price shock: **Heterogeneity** of the shock’s impact on electricity generation costs → the extent of cost increase differ across firms

Focusing on this cost impact heterogeneity, I study:

“Implications of cost impact heterogeneity on the market competition and the subsequent pass-through of cost shocks”

Why Heterogeneity is Important?

- Heterogeneity affects competition and induces markup adjustments
- Markup is an important determinant of cost pass-through
- If we do not account for heterogeneity and strategic markup adjustments, may get a wrong picture of what is going on in this market
Main Contribution of This Paper

- Provide more accurate cost pass-through rate
- Show that cost impact heterogeneity is an important factor of market competition, with a comprehensive analysis of market competition
- Pass-through / Market studies did not focus on cost impact heterogeneity. Why? **Data Limitation** → I develop a novel methodology based on structural bidding model to obtain high-frequency cost estimates and to identify impact heterogeneity
- Implications on empirical pass-through literature: When impact heterogeneity is suspected, we must be aware of potential bias that arise from not accounting for this properly.
Why impact of gas price shock on cost heterogeneous across firms?

**Generation Mix Differences**

- Gas price shock affects the cost of gas-fired units only
- Firms have different composition of gas generation

*(Example): Generation Capacity (MWh) differences across firms*

<table>
<thead>
<tr>
<th>Firm</th>
<th>Total</th>
<th>Gas</th>
<th>Oil</th>
<th>Dual</th>
<th>Coal</th>
<th>Hydro</th>
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</table>
Why impact of gas price shock on cost heterogeneous across firms?

Dual Units

- Dual Units can generate electricity on either gas or oil
  - 28% percent of New England’s gas generators are dual units (as of 2014)

- Dual units can mitigate their impacts from the gas shock by **switching to oil**, especially when the shock is severe
  - Switching fuels is easy
  - Switch to oil when gas price is higher than oil price
  - Depends on the oil inventory on site

- Firms have different composition of dual generation
Why impact of gas price shock on cost heterogeneous across firms?

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- Firms have different composition of dual generation

- Firms with more “non-dual”, “gas” generation are impacted more by the shock than firms with relatively more balanced generation mix
Why impact of gas price shock on cost heterogeneous across firms?

**Increased Volatility in Gas Spot Market**

- Pipeline congestion in New England makes spot gas prices to be volatile

**Daily OTC Gas Transaction Price Differences**

(a) Algonquin Citygate Gas Price

(b) SoCal Citygate Gas Price

- Firms do not purchase gas at the same time
- When gas spot price is volatile, gas procurement prices that enter generation costs could differ across firms
Why impact of gas price shock on cost heterogeneous across firms?

### Increased Volatility in Gas Spot Market
- Pipeline congestion in New England makes spot gas prices to be volatile

#### Daily OTC Gas Transaction Price Differences

- **(a) Algonquin Citygate Gas Price**
- **(b) SoCal Citygate Gas Price**

  - Firms do not purchase gas at the same time
  - When gas spot price is volatile, gas procurement prices that enter generation costs could differ across firms
  - Extent of gas cost increase will be different across (non-dual) gas generators

Note: Price difference between the highest and the lowest transaction prices among the sample: Source(ICE, EIA)
Data vs. Estimate: Why I need a model

Can existing data capture rich heterogeneity in cost impacts?

- Costs data (at firm, generator level) not available

- Especially a problem for gas generators because gas costs vary significantly across firms and generators
  - Gas spot price index (weighted average) is the only available data on gas prices (*Platts, SNL*)
  - Index data doesn't capture heterogeneity

- Even if we have cost data, it may not reflect the opportunity cost
  - hard to get data on what *dual* units planned to use
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To tackle this, I *estimate* cost from a structural bidding model
- Allows estimation of costs that rationalize firms’ bids
- Document heterogeneity from the estimated costs
Heterogeneity of Impact

Strategic Response to the Cost Shock: Auctions

Heterogeneous impact matters because firms compete in auctions in electricity market.

Day-Ahead Wholesale Electricity Market
- Electricity market is cleared via **Multi-unit Uniform Price Auction**
  - Firms submit multiple steps of supply bids \( <\text{price bid,quantity bid}> \) for each of their generating units.

![Diagram showing supply bids](image)
Strategic Response to the Cost Shock: Auctions

Day-Ahead Wholesale Electricity Market

- Electricity market is cleared via Multi-unit **Uniform** Price Auction

- Aggregate Supply Bid: collected by ISO-NE
Strategic Response to the Cost Shock: Auctions

Day-Ahead Wholesale Electricity Market

- Electricity market is cleared via Multi-unit **Uniform** Price Auction

- Uniform Auction: only one firm sets the price of the auction
Strategic Response to the Cost Shock: Auctions

Day-Ahead Wholesale Electricity Market
- Electricity market is cleared via Multi-unit Uniform Price Auction
  - Inelastic Demand: Demand does not affect markup adjustments
Strategic Markup Adjustments and Pass-through

Homogeneous impact, highly correlated shock:

- Price bids of all units increase by the same size $\rightarrow$ no strategic response

- Marginal unit does not add markup $\rightarrow$ Price bid increases by cost shock only $\rightarrow$ Complete Pass-through (e.g. emissions cost shock: Fabra and Reguant, 2014)
Strategic Response to the Cost Shock: Markup Adjustments

**Hetero impact, less correlated shocks:** markup adjustment occurs

- **Marginal firm adds positive markup**
  - Price bid increases by **Cost shock + additional (+) markup**
  - **More than complete pass-through (rate > 1)**
Heterogeneity of Impact

Strategic Response to the Cost Shock: Markup Adjustments

**Hetero impact, less correlated shocks:** markup adjustment occurs

- Marginal firm add very small or negative markup in order to secure dispatch of its marginal unit
  - Price bid increases by **Cost shock + additional (-) markup**
  - **Incomplete** pass-through (rate < 1)
Strategic Response to the Cost Shock: Markups

Overall size of the shock affects markup adjustment

- Large shock pushes cost of gas units closer to the cost of oil

- Gas unit faces more intense competition as shock gets bigger
  - Must compete in a larger pool of competitors, including both gas units and oil units
Strategic Response to the Cost Shock: Markups

Overall size of the shock affects markup adjustment
Strategic Response to the Cost Shock: Markups

Overall size of the shock affects markup adjustment
Heterogeneity of Impact

Strategic Response to the Cost Shock: Markups

Overall size of the shock affects markup adjustment

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Strategic Response to the Cost Shock: Markups

Overall size of the shock affects markup adjustment

Gas-intensive firms more likely to add smaller markups with larger size shock
Model: Optimal Bidding in Multi-Unit Uniform Auction


- **Profit maximization of a Firm $i$ that operates units $j \in J_i$:**

  Firms choose optimal bid ($b_{ikh}$) that maximizes their expected profit (expectation over others’ bids, $b_{-i}$)

  
  
  \[
  \max_{b_{ikh}} \mathbb{E}_{b_{-i}} \left[ \sum_{h=1}^{24} \left( P_h(b_{ih}, b_{-ih}) \left[ Q_{ih}(P_h) - \nu_{ih} \right] \right) - \sum_{j=1}^{J_i} C_{ij} \left( q_{ij}(P(b_i, b_{-i})) \right) \right] \bigg|_{P_h=b_{ikh}}
  \]

- I estimate parameters of the model using the first-order necessary conditions of optimal bids
Model: Optimal Bidding in Multi-Unit Uniform Auction

**First-order Necessary Condition:**

\[ E \left( \frac{\partial P_{ht}}{\partial b_{ijkht}} \left[ (Q_{iht}(P_{ht}) - \nu_{iht}) + (P_{ht} - C'_{ij}(Q_{ijht}(P_{ht})) \right] \frac{\partial Q_{iht}(P_{ht})}{\partial P_{ht}} \right) = 0 \]

where,

\[ C'_{ij}(Q_{ijht}(P_{ht})) = mc_{ij} + \epsilon_{ijkht} \]  
(Marginal Cost)

\[ \nu_{iht} = \gamma_{ih} Q_{ht} + \epsilon_{ht} \]  
(Forward Contract)

**Parameters:** Marginal Cost \((mc_{ij})\) and forward contract parameters \((\gamma_{ih})\)

**Assumptions on Parameters (required for identification):**

- **Marginal cost:** constant, defined at the unit-level \((j)\), and do not vary across hours

- **Forward contract:** defined at the firm level \((i)\), and is common across units. One parameter per hour.
Identifying the cost impact heterogeneity:

Q: Does variations in estimated costs reveal the heterogeneity of the impacts across firms?
A: No. This variation consists of heterogeneities in efficiencies (heat rates) and impacts.
Marginal Cost Decomposition: Additional Parameters

Identifying the cost impact heterogeneity:
Q: Does variations in estimated costs reveal the heterogeneity of the impacts across firms?
A: No. This variation consists of heterogeneities in efficiencies (heat rates) and impacts.

Simple production technology enables decomposition of Marginal Cost of Electricity Generation

\[ mc_{ij} = hr_{ij}(FP_{ij} + e_{ij} \tau) \]

- \( hr_{ij} \): unit \( j \)'s physical efficiency
- \( FP_{ij} \): unit \( j \)'s fuel price
- \( e_{ij} \tau \): emission price
Marginal Cost Decomposition: Additional Parameters

Identifying the cost impact heterogeneity:

Q: Does variations in estimated costs reveal the heterogeneity of the impacts across firms?
A: No. This variation consists of heterogeneities in efficiencies (heat rates) and impacts

- Simple production technology enables decomposition of Marginal Cost of Electricity Generation

\[ mc_{ij} = hr_{ij}(FP_{ij} + e_{ij}\tau) \]

- \( hr_{ij} \): unit j’s physical efficiency
- \( FP_{ij} \): unit j’s fuel price
- \( e_{ij}\tau \): emission price

- Want to identify heterogeneity resulting from the gas price shock alone
  \( \rightarrow \) partial out heat rates and estimate fuel price component of the marginal cost (implied fuel prices)
Marginal Cost Decomposition: Additional Parameters

Advantages of using Implied Fuel Prices

- Identify dual unit’s fuel switch decision → used in simulation
- Can directly compare Implied fuel price estimates to fuel price index data
- Fuel Price Information at generating unit-level (data not available): alternative to gas price index data → used in the reduced form regression

Estimate heat rates and then implied fuel prices

- Need heat rates to partial them out
- Exploiting this decomposition and using two different samples that differ in gas price stabilities, I estimate different set of parameters from each sample
- Goal: obtain estimates of Implied fuel price $FP_{ij}$ for each day when gas price shock was present
Sample 0 (w/o shock) and Sample 1 (w/ shock)

Total sample: Winters of 2013 and 2014 (Sep. - Mar.)
- Sample 0: Gas Price is stable → around $4/MMbtu (180 days)
- Sample 1: Gas Price is volatile → above $4/MMbtu (190 days)
Heat Rate and Implied Fuel Price Estimation

**(Sample 0) Gas price is stable:**

\[ mc_{ijt,0} = hr_{ij} \left( FP_{0,ijt,\text{gas}} + e_{ij\tau} \right) \]

Can use Gas price index data for \( FP_{0,ijt,\text{gas}} \), because:
- Gas price doesn’t differ across firms and over time
- Gas price index: weighted-average → accurate measure of ex-ante cost
- **Estimate** \( hr_{ij} \) from Sample 0

**(Sample 1) Gas price volatile:**

\[ mc_{ijt,1} = hr_{ij} \left( FP_{1,ijt,\text{gas}} + e_{ij\tau} \right) \]

Cannot use Gas price index data for \( FP_{1,ijt,\text{gas}} \), because:
- Gas prices differ across firms and over time
- **Estimate** \( \hat{mc}_{ijt,1} \)
- Can use Sample 0 \( \hat{hr}_{ij} \) in Sample 1:
  - physical efficiency is invariant to shock
- **Back out implied fuel price** \( FP_{1,ijt,\text{gas}} \) from \( \hat{mc}_{ijt,1} \) using estimated \( \hat{hr}_{ij} \)
Estimation

Estimate parameters from each sample ($T$) using GMM, with moments constructed based on the empirical analogue of first-order conditions

- **Empirical analogue of First-order Conditions:**

  $$m_{ijkht}^T(\theta; bw, S) = \frac{1}{S} \sum_{s=1}^{S} \frac{\partial \hat{P}_h^s}{\partial b_{ijkh}} \left( (Q_{ikht}^s - \nu_{iht}(\gamma_i)) + (b_{ijkht} - mc_{ij}') \frac{\partial \hat{RD}_{iht}^s}{\partial \hat{P}_{ht}} \right)$$

- **Parameters estimated from each sample:**
  - Sample 0, estimate $\theta = \{hr_{ij}, \gamma_{ih}\}$: heat rate and forward contract
  - Sample 1, estimate $\theta = \{mc_{ijt,1}\}$, and back out $FP_{ijt}$. 

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Data

- Auction Bidding Data: ISO-New England Day-ahead Electricity Market Supply Offer and Demand bids data

- Firm and Generating Unit Characteristics Data: ISO-NE Seasonal Claimed Capacity data

- Fuel Price Data:
  - Daily Natural Gas Spot Prices Index Data at two citygates in New England (Algonquin Citygate, Tenn Zone 6/200L), *Natural Gas Intelligence, SNL*
  - Daily Petroleum Spot Prices (FO2, FO6, Jet Fuel, Kerosene), *EIA*

- Emissions Permit: RGGI auction data, *EPA*
Estimation Result: Heat Rates and Forward Contract Parameter

Heat Rate ($hr$) Estimates

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Average heat rate(MMbtu/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>9.09</td>
</tr>
<tr>
<td>Petroleum</td>
<td>12.39</td>
</tr>
<tr>
<td>Dual Units</td>
<td>11.01</td>
</tr>
</tbody>
</table>

e.g.) EIA reported Heat Rates:
- Natural Gas Units (7.6 - 11.3)
- Petroleum Units (9.9 - 13.5)

Forward Contract Rate ($\gamma$) Estimates

Varies across firms, hours: average = 47 %
Marginal Cost Estimates by Fuel Types of Generating Units

- Daily marginal cost estimates averaged within each fuel type category
- Average values plotted against the gas price index values of each day

Note: three period moving average taken to smooth lines
**Implied Fuel Price Estimates**

**Colored lines:** Fuel Price Estimates ($/MMbtu)
**Dash line:** Gas Spot Price Index Data ($/MMbtu)

**Firm 9: Non-dual Gas units only**

- Estimated gas prices track the gas spot indices
Implied Fuel Price Estimates

Firm 33: Operate Both Non-Dual and Dual Gas Units

- Implied fuel prices of Non-dual gas units more dispersed across units
**Firm 33: Operate Both Non-Dual and Dual Gas Units**

- Implied fuel prices of Non-dual gas units more dispersed across units

- **Dual unit’s Fuel Switch decision**: can be detected from the red line → implied fuel prices of dual units do not fluctuate as the gas price indices does
Implied Fuel Price Estimates

Firm 8: Dual Gas unit and Oil units

Implied Fuel Price Estimates: Firm 8

- Oil unit
- Dual unit
- Gas Price Index
Fuel Switch Decisions of Dual Units Identified

Note: Total 50 Dual units in the sample
Implied Fuel Price Estimates: Gas Units Only

Cross-Firm Dispersion in Implied Gas Price Estimates

Heterogeneity Increases with the overall size of the Gas price Shock

Mean / Std. of Implied Gas Price Estimates

Smoothed mean of Implied gas price
○ mean of Implied gas price
standard dev. of implied gas price

Note: excluded dual units that switched to oil
Estimation Results

Implied Fuel Price Estimates: Gas Units Only

Cross-Firm Dispersion in Implied Gas Price Estimates: Non-Dual vs. Switched Dual

Heterogeneity increases with the overall size of the gas price shock

Mean / Std of Implied gas price estimates – gas used vs. switched

Note: “gas used” does not include estimates of dual units that switched to oil
Markup Analysis: Overview

- Markup: Strategic Component of a Price bid

\[ \text{Bid} = \text{Marginal Cost} + \text{Markup} \quad (1) \]

- Market power exercised by adding large markups, expecting to manipulate the market price in ex-ante

- Want to explore how markup adjustments of firms are related to their cost impacts from the gas price shock

1. (Semi-counterfactually) Simulate Markups Using First-order Approach:
2. Compare Markups Across Two Groups of Firms that differ in Cost Impacts: “Gas-Intensive” vs. “Non-intensive”
First-Order Approach: Markup Adjustment Simulation

I simulate a firm’s Endogenous Markup Adjustment to a small gas price shock perturbation.

- First-order condition used for the simulation:
  \[
  \Delta pbid_i = \underbrace{mc'_i(q_i) - mc_i(q_i)}_{\text{Direct cost shock}} + \underbrace{|\frac{\partial p'(q'_i)}{\partial q'_i}| \tilde{q}'_i - |\frac{\partial p'(q_i)}{\partial q_i}| \tilde{q}_i}_{\text{Markup Change}}
  \]

- Firm \(i\)’s cost shock enters through “Direct cost shock” part.
- Cost shocks of other firms enter through residual slope \(|\frac{\partial p'(q_i)}{\partial q_i}|\tilde{q}_i\) of the “Markup Change” component.

- Marginal approach: More informative of pass-through:
  - pass-through rate: price response to a unit cost shock
First Order Approach: Simulation Steps

Assume that firms initially play strategy of **increasing the price bids** of their units affected by the shock by the **size of the cost perturbation**

**Cost perturbation**: Impose 10 cents/MMbtu gas price shocks → approximately $1/MWh size shock to marginal costs
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Assume that firms initially play strategy of increasing the price bids of their units affected by the shock by the size of the cost perturbation.

Cost perturbation: Impose 10 cents/MMbtu gas price shocks → approximately $1/MWh size shock to marginal costs.

(Step 1) All firms increase price bids of their Gas and Dual units that didn’t switch fuels by $ hr* 0.1 /MWh.
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**Cost perturbation:** Impose 10 cents/MMbtu gas price shocks → approximately $1/MWh size shock to marginal costs

**(Step 1)** All firms increase price bids of their **Gas** and **Dual units that didn’t switch fuels** by $ 0.1 /MWh

**(Step 2)** Recompute the new market price with perturbed Supply bid curve and Demand
  - Compute new $Q_{infra}$ and $\partial RD_i/\partial p$(slope of Residual Demand) under new price and bid curve
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- **(Step 2)** Recompute the new market price with perturbed Supply bid curve and Demand
  - Compute new $Q_{infra}$ and $\partial RD_i / \partial p$(slope of Residual Demand) under new price and bid curve

- **(Step 3)** Measure the **Endogenous Change in Markups** implied by this bid shift:

$$\text{markup}_1 - \text{markup}_0 = \frac{Q_{infra,1}}{\partial RD_{i,1} / \partial p} - \frac{Q_{infra,0}}{\partial RD_{i,0} / \partial p}$$  \hspace{0.5cm} (2)
Example of a firm’s Residual Demand before and after perturbation
Change in Markup: Hard-hit vs. Not

- Plotted density of days with similar levels of overall gas price shocks (gas price indices) and market demands
- Plotted density separately for Gas intensive firm vs. Non-intensive firms

Days when gas price index $\leq 6$/mmbtu

$\rightarrow$ Lack of Markup Response (close to 0)
Change in Markup: Hard-hit vs. Not

Similar days when $18 \leq \text{Gas price index} \leq $28/MMBtu

- **gas price $18 auctions**
  - Dashed line: less gas
  - Solid line: more gas
  - Note: bw1 = 0.15, bw2 = 0.1

- **gas price $24 auctions**
  - Dashed line: less gas
  - Solid line: more gas
  - Note: bw1 = 0.3, bw2 = 0.15

- **gas price $28 auctions**
  - Dashed line: less gas
  - Solid line: more gas
  - Note: bw1 = 0.15, bw2 = 0.1
Change in Markup: Hard-hit vs. Not

Similar days when Gas price Index \( \geq \$38/\text{MMBtu} \)

Summary of Results:
- Shock induces markup adjustments
- Adjustment patterns differ across Hard-hit and Not hard-hit firms: Not hard-hit firms add higher markup than Hard-hit firms
Simulated Cost Pass-through Rates: Idea

Use **Endogenous Markup change** simulated from First-order Approach Simulation

- Market clearing Price of auction = Price bid of ex-post marginal unit
  - Simulated $\Delta$ Price bid of ex-post marginal unit ≡ Simulated $\Delta$ Price

- Assume Marginal unit does not change with a small perturbation

![Diagram showing supply and demand curves with cost shock and simulated markup changes](image-url)
Simulated Pass-through Rates are Heterogeneous

Summary of Simulated Pass-through Rates

- **Mean** of pass-through rates is 0.97 (≈ 1) → on average complete pass-through

- Rates are Heterogeneous: range between [0.004, 2.198], with std.dev = 0.204

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<thead>
<tr>
<th>Summary statistics</th>
<th>Simulated pass-through rates, ( \rho_s )</th>
</tr>
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<tbody>
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<tr>
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<tr>
<td>Max</td>
<td>2.198</td>
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<td>S.d.</td>
<td>0.204</td>
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<td>Obs</td>
<td>2,660</td>
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</table>
Source of Pass-through Rate Heterogeneity: Heterogeneous Markups

- Each auction has different marginal units → different impacts on costs → different incentives for markup adjustment
- Regression of pass-through rates on characteristics of marginal units

<table>
<thead>
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<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
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<tbody>
<tr>
<td>( \rho_s )</td>
<td></td>
<td>( \rho_s )</td>
</tr>
<tr>
<td>Gas intensive</td>
<td>-0.046***</td>
<td>-0.032**</td>
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<td></td>
<td>(0.008)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>( Gl \times \ln(Dgas) )</td>
<td>-0.041**</td>
<td>-0.076***</td>
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<td>( \ln(Dgas) )</td>
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<td>0.020</td>
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<td></td>
<td>(0.006)</td>
<td>(0.012)</td>
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<td>Constant</td>
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<td>0.993***</td>
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<tr>
<td></td>
<td>(0.0048)</td>
<td>(0.009)</td>
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Observations 2,223 Observations 2,229

Having “Hard-hit” firm (add small markup) as marginal results in lower pass-through rate than having less hard-hit firms.
Source of Pass-through Rate Heterogeneity: Heterogeneous Markups

- Each auction has different marginal units → different impacts on costs → different incentives for markup adjustment
- Regression of pass-through rates on characteristics of marginal units

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<tr>
<td>$GI * \ln(Dgas)$</td>
<td>-0.041**</td>
<td>-0.076***</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.021)</td>
</tr>
<tr>
<td>$\ln(Dgas)$</td>
<td>0.002</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.005***</td>
<td>0.993***</td>
</tr>
<tr>
<td></td>
<td>(0.0048)</td>
<td>(0.009)</td>
</tr>
</tbody>
</table>

Observations: 2,223

- Having “Hard-hit” firm (add small markup) as marginal results in lower pass-through rate than having less hard-hit firms
Reduced Form Pass-through of Cost shock Regression

Simulation vs. Reduced form

- Simulation requires a structural model

- Reduced form Regression is more commonly used
  - Type of analysis regulators (EPA, EIA) would conduct
  - Common in empirical pass-through literature (macro, international)

What I do in this section

- Compare naive reduced-form pass-through estimates to the simulated pass-through rates → check the bias
- Show that the main cause of this bias is the use of gas cost measure that doesn’t capture heterogeneity

Jump to results
Specification: Reduced form Pass-through

- Follow Fabra and Reguant (2014): Regress Electricity price ($p_{th}$) on Gas Cost ($hr_{th}G_{th}$) of a marginal gas unit

\[ p_{th} = \rho \cdot hr_{th}G_{th} + \beta_0X_{th}^D + \beta_1I_{th} + \epsilon_{th} \]

- Hourly auctions ($th$) where Gas units are marginal are selected as a sample
- Variations in Prices and Gas costs across auctions identify $\rho$

- $\rho$: Average pass-through rate
- $hr_{th}G_{th}$: Gas cost - heat rate of the marginal unit multiplied by the gas price
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What problems arise when using reduced form analysis when **Heterogeneity** is present?

- (1) Homogeneous rate parameter: One single “Average” pass-through rate is estimated
- (2) Gas Cost Measurement Problem: Gas Spot price Index data is not a good measure of unit-level gas prices
- (3) How to account for dual units that switched fuel: again a measurement problem arise if switch decision is hard to observe
Specification: Reduced form Pass-through

- Follow Fabra and Reguant (2014): Regress Electricity price ($p_{th}$) on Gas Cost ($hr_{th}G_{th}$) of a marginal gas unit

$$p_{th} = \rho hr_{th}G_{th} + \beta_0 X^D_{th} + \beta_1 l_{th} + \epsilon_{th}$$

- Hourly auctions ($th$) where Gas units are marginal are selected as a sample
- Variations in Prices and Gas costs across auctions identify $\rho$

- $\rho$: Average pass-through rate
- $hr_{th}G_{th}$: Gas cost - heat rate of the marginal unit multiplied by the gas price

Three Specifications that use different Gas Cost ($G_{th}$) Measures

<table>
<thead>
<tr>
<th>Spec.</th>
<th>Heat Rate ($hr_{th}$)</th>
<th>Gas Price ($G_{th}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Homo $hr$ (EIA estimate)</td>
<td>Homo Gas Price Index Data</td>
</tr>
<tr>
<td>(2)</td>
<td>Hetero $\hat{hr}_{th}$ estimate</td>
<td>Homo Gas Price Index Data</td>
</tr>
<tr>
<td>(3)</td>
<td>Hetero $\hat{hr}_{th}$ estimate</td>
<td>Hetero Implied Gas price estimate ($\hat{FP}_{th}$)</td>
</tr>
</tbody>
</table>
### Reduced form Estimation Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>( \rho(\text{cost pass-through rate}) )</th>
<th>( \bar{h}_{th} = \text{Average hr} )</th>
<th>( \hat{h}_{th} = \text{Estimated hr} )</th>
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<tbody>
<tr>
<td>full sample</td>
<td>(1) 0.481 (0.042)</td>
<td>(2) 0.457 (0.052)</td>
<td>(3) 1.118 (0.040)</td>
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<tr>
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<td></td>
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<td>(1) 0.585 (0.063)</td>
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<td>3,129</td>
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<td>3,110</td>
</tr>
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- Pass-through rates in (1) and (2) significantly lower than in (3)
- Gas price measure (\( G_{ht} \)) heterogeneity is the key factor that causes difference

- Only (3) corresponds to what Simulated rates suggest (Average = 0.97)
- Reduced form estimation results improved by using Implied Gas price estimated from the structural model (which reflects heterogeneity)
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<tr>
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<th>$\hat{h}_{th}$ = Estimated hr</th>
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<tr>
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Only (3) corresponds to what **Simulated rates** suggest (**Average = 0.97**).
- Reduced form estimation results improved by using **Implied Gas price** estimated from the structural model (which reflects heterogeneity).
Conclusion

- Identify the sources of and document heterogeneous impact of the gas price shock with a structural estimation of bidding model

- Cost impact heterogeneity induces strategic markup adjustments

- These markup adjustments are reflected in pass-through rates, making pass-through rates to be heterogeneous as well

- Firms in the New England electricity market completely passed on the gas cost shock to electricity prices, on average.

- Failing to account for the heterogeneity in cost impacts when conducting a reduced form regression may result in inaccurate pass-through estimates
New England Electricity Market clears via Auction

Day-ahead Wholesale Electricity Market

- Market cleared via Multi-unit Uniform Price Auction

- Electricity Generating firms simultaneously submit supply offer bids for the 24 hours of the next day (24 auctions each day)

- Each generating unit\((j)\) of firm\((i)\) allowed to submit a step function up to 10 steps

- ISO-NE clears the market each hour and determines the price where aggregate supply offer equates aggregate demand (fixed, price sensitive bids)
  - Hourly Prices\((P_h)\) and Unit dispatch order determined
  - Each unit supplies committed amount of electricity at settled price
Gas Spot price Index and Oil Spot prices

- Oil(No.2, No.6, KER) price is between $16/MMbtu and $22/MMbtu
  - Gas price < Oil price → Gas units compete with each other

- Gas price \sim Oil price \approx around 20 $/MMbtu
  → compete with both gas and oil units

- Gas price > Oil price: Gas unit becomes the highest cost generation technology
GMM Moment Condition

\[ \sum_{t=1}^{T} \sum_{k=1}^{K} Z'_{0,ht} m_{ijkht}^0 (hr_{ij}, \gamma_{ih}) = 0 \]  
(3)

\[ \sum_{h=1}^{H} \sum_{k=1}^{K} Z'_{1,ht} m_{ijkht}^1 (mc_{ijt,1}; \hat{hr}_{ij}, \hat{\gamma}_{ih}) = 0 \]  
(4)

- **Instruments:** measurement error or endogeneity of markup terms
  
  \[ Z_0 = \{ \text{forecasted demand, daily temperature} \} \]
  \[ Z_1 = \{ \text{demand forecast error} \} \]
Expectation Approximations: Resampling

Need to approximate expectation over others’ bids $b_{-i}$ (belief) in order to construct the empirical analogue of F.O.C.

Resampling Method

- Resampling procedure is used to approximate expectations (Hortacsu and McAdams, 2010; Reguant, 2014; Ryan, 2015)
  - Simulate the beliefs of one firm $i$ about the other firms’ bids (strategies).
  - Assumes that observed bids is the equilibrium belief

Similar Days

- Allow for ex-ante observable asymmetries between days by performing the resampling within ex-ante symmetric group of similar days.
- Randomly draw days from a set of similar days
- Similar day selection criteria:
  - Sample 0: Demand forecast and day type (weekdays, weekend) were used
  - Sample 1: More Supplier side criteria (gas days similarity, gas prices, cold days in the past etc.) which governs similarity in firms’ bids in volatile time period.
Identification

Identification of both heat rate \((hr_{ij})\) and forward contract parameter \((\gamma_{ih})\) of Sample 1 estimation is possible by imposing reasonable restrictions on these parameters (Reguant, 2014)

Restrictions

- Heat rate \((hr_{ij})\): Defined at a unit level\((j)\) and do not vary across hours
- Forward Contract \((\gamma_{ih})\): Defined at a firm-hour level
  - A firm can have 24 forward parameters which are common across units owned by the firm
- Both \(hr_{ij}\) and \(\gamma_{ih}\) are relatively constant over the Sample 0: Single parameter per sample
Identifications of \((\gamma_{ih}, hr_{ij})\)

- Given i (and j), \(b^*\) and \(Q^*\) varies across hours (h) and days (t).
- \(\gamma_{ih}\) is identified by the unit-specific variations of \(b^*_{ijth}\) and \(Q^*_{ith}\) across t at a given hour (h).
- Identifying \(hr_{ij}\) is straightforward once the \(\gamma_{ih}\) parameters are identified.
Difference between Bid Markup and Simulated Markup

\[
b_{ijkht} - m_{cijkht} = \frac{\mathbb{E}_-i[Q_{ijkht} - \nu_{iht}]}{\mathbb{E}_-i[\partial RD_{iht}/\partial p_{ht}]}\]

1. Bid markup: measure the portion of strategic component of the price bid net of marginal cost estimate, \(\widehat{mc}_{ij}\)

2. Markup Simulation using First-order Approach:
   - More Marginal approach
   - Simulate endogenous markup changes following a small-sized cost shock
   - More suitable for analyzing the response to a change in costs, i.e. cost shock, and more relevant for Pass-through measurement
Pre and Post shock Period Bid Markups

(a) Pre-shock Bid Markup Distribution
(b) Post-shock Bid Markup Distribution

- Firms added larger bid markup in post-shock than in pre-shock period
- Gas-intensive firms added less bid markup than Non-intensive firms
First-Order Approach Simulation: Conditions

- Size of the perturbation has to be small: Post-perturbation equilibrium must not depart much from local equilibrium

- Firms’ behavior (best response) and set of beliefs about competitors’ bids are continuation of their local equilibrium

- Alternative to full counterfactual analysis which is challenging
  - Do not have information of bid distribution in a counterfactual situation; makes a full structural counterfactual analysis difficult
  - Multiple equilibria problem of supply function equilibrium (Klemperer and Meyer, 1989)
Simulated Cost Pass-through Rates

- Pass-through Rates Obtained for Total 2,660 Hourly Auctions
- Ex-post Marginal Units Used Only (Ex-post Marginal Units Identified From Data)

**Simulated Price bid Change of auction s**

- Sum of marginal unit’s cost shock and simulated endogenous change in markup:

\[ \Delta p_s = \Delta b_{s,\text{margin}} = \Delta mc_{s,\text{margin}} + \Delta \widehat{\text{markup}}_{s,f,\text{margin}} \]

\[ \rightarrow \Delta \widehat{\text{markup}}_{s,f,\text{margin}} \text{ obtained from first-order approach simulation} \]

**Pass-through rate of auction s**

\[ \text{pass-through}_s = \frac{\Delta p_s}{\Delta mc_{s,\text{margin}}} \]
## Reduced form Estimation Results

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</tr>
<tr>
<td>below $15$</td>
<td>0.833 (0.085)</td>
<td>0.882 (0.068)</td>
<td>0.979 (0.020)</td>
</tr>
<tr>
<td>btw $15$ and $25$</td>
<td>0.606 (0.119)</td>
<td>0.520 (0.096)</td>
<td>1.007 (0.052)</td>
</tr>
<tr>
<td>above $25$</td>
<td>0.306 (0.069)</td>
<td>0.302 (0.070)</td>
<td>1.498 (0.216)</td>
</tr>
<tr>
<td>Observations(full)</td>
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### Subsample Regression: Pass-through Rates Heterogeneous