Energy Prices, Pass-Through, and Incidence in U.S. Manufacturing

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Overview

How do changes in energy costs affect manufacturing markups, marginal costs?
Pass-Through?
Incidence?

Motivation

- Energy important for manufacturing
- Greenhouse gas regulation, Middle East conflict, fracking, ...
- Regressive? Political economy for industry?

Data: administrative, confidential, plant-level.

Approach:

- Recover marginal costs using production functions and firm FOC
- Estimate pass-through
- Derive, use sufficient statistics formula for incidence.

Motivation

Pass-through and incidence important, controversial

A U.S. cap-and-trade program for CO2 would have a "devastating impact to manufacturing" due in part to inability "to adjust the price of their goods and services quickly enough to match potentially steep energy cost increases"

– National Association of Manufactures (Streeter 2009)

"Americans will be hit repeatedly with higher prices as businesses pass higher costs onto consumers. . . . If a company had to absorb the costs, high energy costs would shrink profit margins."

– Heritage Foundation (Loris and Jolevski 2014)

Motivation

Limited available evidence

"More research that carefully quantifies the effects of environmental policies on the prices of final goods is also needed. Existing research typically assumes that firms will have the ability to fully pass along the costs of environmental policies in the form of higher consumer prices. Under many circumstances, this assumption may not be applicable."

– Bento (2013)

"Empirical studies on the extent to which the costs of environmental policies are passed forward into higher prices of consumer products would be extremely valuable; at present, empirical analyses typically assume 100% pass-through . . ."

– Sigman, Walls, and Williams (2006)

Results

1. Pass-through is incomplete.
   - Overall marginal cost pass-through rate $\approx 75\%$
2. Consumers bear lower share of welfare burden than standard methods imply.
   - Conventional methods assume complete pass-through, perfect competition
   - Our approach: consumers bear 20-70% less of the burden

Existing Research and Contributions

- Economy-wide energy price incidence
  (Bovenberg & Goulder 2001, Fullerton & Heutel 2007, Hasset et al. 2009, Grainger & Kolstad 2010, Fullerton & Heutel 2010, Williams et al. 2014)
  - New here: Incomplete pass-through, imperfect competition
- Imperfect Competition and Environmental Externalities
  (Buchanan 1969, Barnett 1980, Ryan 2012, Fowlie et al. 2016)
  - New here: Multiple industries, flexible model
- Microeconometric pass-through
  (Doyle & Samphanththarak; Marion & Muehlegger 2011, Fabra & Reguant 2014, Miller et al. 2015)
  - New here: Multiple factors
- Pass-through of other costs
  (De Loecker et al. 2016, Goldberg & Hellerstein 2008, Gopinath et al. 2011, Campa & Goldberg 2005, Poterba 1996, Cabral et al. 2015, Duggan et al. 2014, Harasztosi & Lindner 2015)

Existing Research and Contributions

New here? Analyze energy price incidence while accounting for:

- Imperfect competition
- Multiple industries
- Incomplete pass-through
- Factor substitution

Arbitrary market structure, demand system

Bottom Line: Methodology to measure incidence and pass-through flexibly in any industry with price data and cost-minimizing firms.

Road map for this talk

- Theory of Incidence
- Data
- Methodology and Results
- Conclude

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Theory of Incidence

Definitions

Incidence, $I \equiv \frac{dCS/d\tau}{dPS/d\tau}$ Pass-Through Rate, $\rho \equiv \frac{dP}{d\tau} = \frac{1}{1+\frac{\epsilon_D}{\epsilon_S}}$

Cost-Shift Rate, $\gamma \equiv \frac{dMC}{d\tau}$

Basic results

$$I^{Competitive} = \frac{\rho}{\gamma - \rho} \qquad I^{Monopoly} = \frac{\rho}{\gamma}$$

Intuition [perfect competition]: envelope theorem

- Increasing τ decreases CS by Q^* times change in consumer prices, ρ
- Increasing τ decreases PS by Q^* change in producer margins, $\gamma - \rho$

Monopoly Demand Forms

Theory of Incidence

Incidence of Input Tax under Oligopoly

$$I^{Oligopoly} = \frac{\rho}{\gamma - (1 - L \times \epsilon_D)\rho}$$

Important notes:

- Parameters
  - Pass-through ρ
  - Cost-shift γ
  - Lerner Index $L = (P - MC)/P$
  - Demand elasticity $\epsilon_D \equiv -[dQ/dP][P/Q]$
- Incidence of output, input taxes differ when $\gamma \neq 1$ (extends Weyl, Fabinger 2013)

Asymmetric Firms

Theory of Incidence

Incidence of Input Tax under Oligopoly

$$I^{Oligopoly} = \frac{\rho}{\gamma - (1 - L \times \epsilon_D)\rho}$$

Important notes:

- Version we take to the data:

$$I^{Oligopoly} = \frac{\rho_{MC}}{1 - (1 - L \times \epsilon_D)\rho_{MC}}$$

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Data

Census of Manufacturers, 1972-1997

- Quinquennial plant-product-year level micro data from U.S. Census.
- Sample restrictions:
  - Homogeneous products (need unit prices)
  - Single-product plants
  - Drop imputed data (Unisys)
- Boxes, Bread, Cement, Concrete, Gas, Plywood

Manufacturing Energy Consumption Survey, ASM Fuel Trailers

- Plant-level inputs: coal, natural gas, oil, electricity

State Energy Data System

- National inputs (BTU) for electricity: coal, natural gas, oil.

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  2. Effects of energy price shocks on marginal costs, markups, output prices
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Methodology - Markups

Some Intuition: How do we get markups from output elasticities of the production function?

$$Y = AK^{\alpha}L^{\beta}$$

- F.O.C. of firm relates output elasticity of a variable input (e.g. materials) to revenue share of input and markup (Hall 1988; De Loecker, Warzynski 2012)
- Under imperfect competition, input growth is associated with disproportional output/revenue growth
- Deviation between output elasticity of input and revenue growth identifies markup

Methodology - Markups

Markup Mechanics: Quick illustration/derivation

- General production function with hicks-neutral productivity:

$$Q = F(\mathbf{V}, \mathbf{K})\Omega$$

$\mathbf{V}$: variable input (materials); $\mathbf{K}$: dynamic input (capital, labor); Ω: TFP

- Firm minimizes cost of variable input(s), conditioning on dynamic inputs
- Lagrangian:

$$L(\mathbf{V}, \mathbf{K}, \lambda) = \sum_{v=1}^{V} P^V V^V + \mathbf{rK} + \lambda[Q - Q(\mathbf{V}, \mathbf{K}, \Omega)]$$

Markups

- The marginal cost of production (for a given level of output) is λ
  - i.e. since $\frac{\partial L}{\partial Q} = \lambda$
- FOC for variable input (e.g., materials):

$$\frac{\partial L}{\partial V^v} = P^v - \lambda \frac{\partial Q(.)}{\partial V^v} = 0$$

$$\frac{\partial Q(.)}{\partial V^v} \frac{V^v}{Q} = \frac{1}{\lambda} \frac{P^v V^v}{Q}$$

$$\underbrace{\frac{\partial Q(.)}{\partial V^v} \frac{V^v}{Q}}_{\text{Output elasticity}} = \underbrace{\frac{P}{\lambda}}_{\text{Markup}} \times \underbrace{\frac{P^v V^v}{PQ}}_{\text{Input's share of revenue}}$$

- Markup identified using output elasticity [estimate] and revenue share [data]
- If we observe prices in the data, we can calculate marginal costs from estimated markups: **MC = Price - Markup**

Recovering Markups: Summary

1. Firm's FOC implies:
   - Markup equals output elasticity divided by revenue share
   - For a flexible input like materials

$$\underbrace{\frac{P_{it}}{\lambda_{it}}}_{Markup} = \underbrace{\left[\frac{\partial Q_{it}(\cdot)}{\partial V_{it}} \frac{V_{it}}{Q_{it}}\right]}_{Output\ \ Elasticity} \underbrace{\left[\frac{P_{it}^{V} V_{it}}{P_{it} Q_{it}}\right]^{-1}}_{Revenue\ \ Share}$$

   - Intuition: Under imperfect competition, input growth is associated with disproportional revenue growth

2. Estimate output elasticity via production functions (Ackerberg et al. 2015)
   - Translog, gross-output production function with 3 factors (K, L, M)
   - Output is quantity (not revenue), avoiding output price bias

3. Compute marginal costs from price = marginal cost $\times$ markup

Production Function Estimation and Output Elasticities

	Energy Cost Share (1)	Output Elasticities: Labor (2)	Output Elasticities: Materials (3)	Output Elasticities: Capital (4)	Returns to Scale (5)	Markup (6)	Observations (7)
Boxes	0.02	0.04	0.95	0.04	1.00	1.47	1414
Bread	0.02	0.28	0.63	0.09	1.13	1.20	248
Cement	0.32	0.91	1.08	0.19	2.46	2.30	229
Concrete	0.02	0.11	0.68	0.16	1.09	1.12	3369
Gasoline	0.84	0.01	0.99	0.03	1.02	1.11	284
Plywood	0.02	0.02	0.95	0.11	0.92	1.48	139
Mean	0.02	0.10	0.070	0.14	1.09	1.15	5683

Note: Translog, 3-factor (K, L, M), gross-output production function. Materials include electricity+fuels. This table shows mean values of energy cost shares, output elasticities, and markups. An observation is a plant-year.

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Effects of energy price shocks on marginal costs, markups, output prices

Fixed Effects Regression

$$Y_{it} = \beta_1 E_{it} + X'_{it}\gamma + \eta_i + \epsilon_{it}$$

- Y_{it}: Plant-level Marginal Costs, Markups, or Prices
- E_{it}: Energy Price
- X_{it}: vector of controls (e.g. industry$\times$year, region$\times$year FE)
- η_i: plant fixed effects

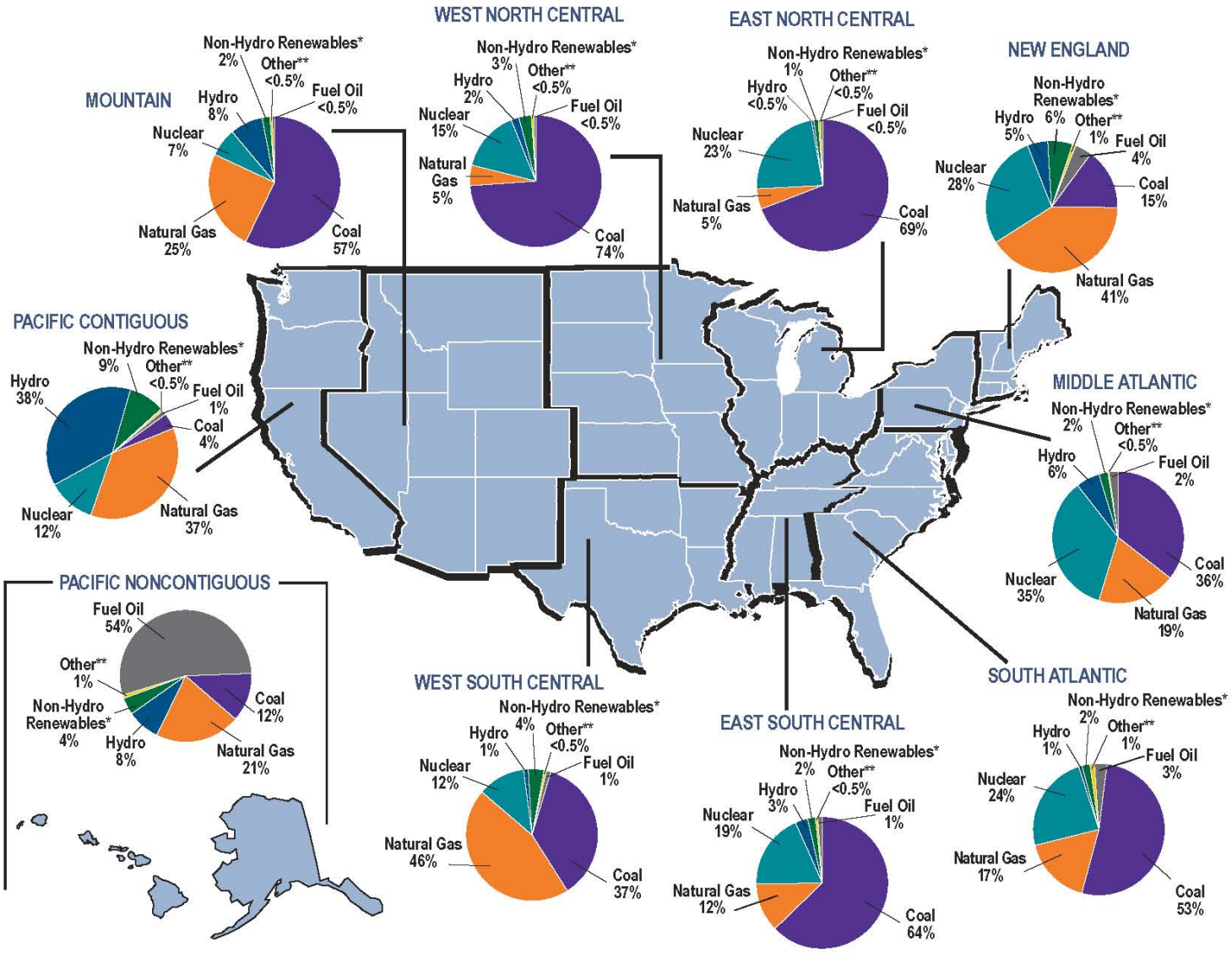
Econometric Issue: Energy prices E_{it} are endogenous

- Likely correlated with local demand

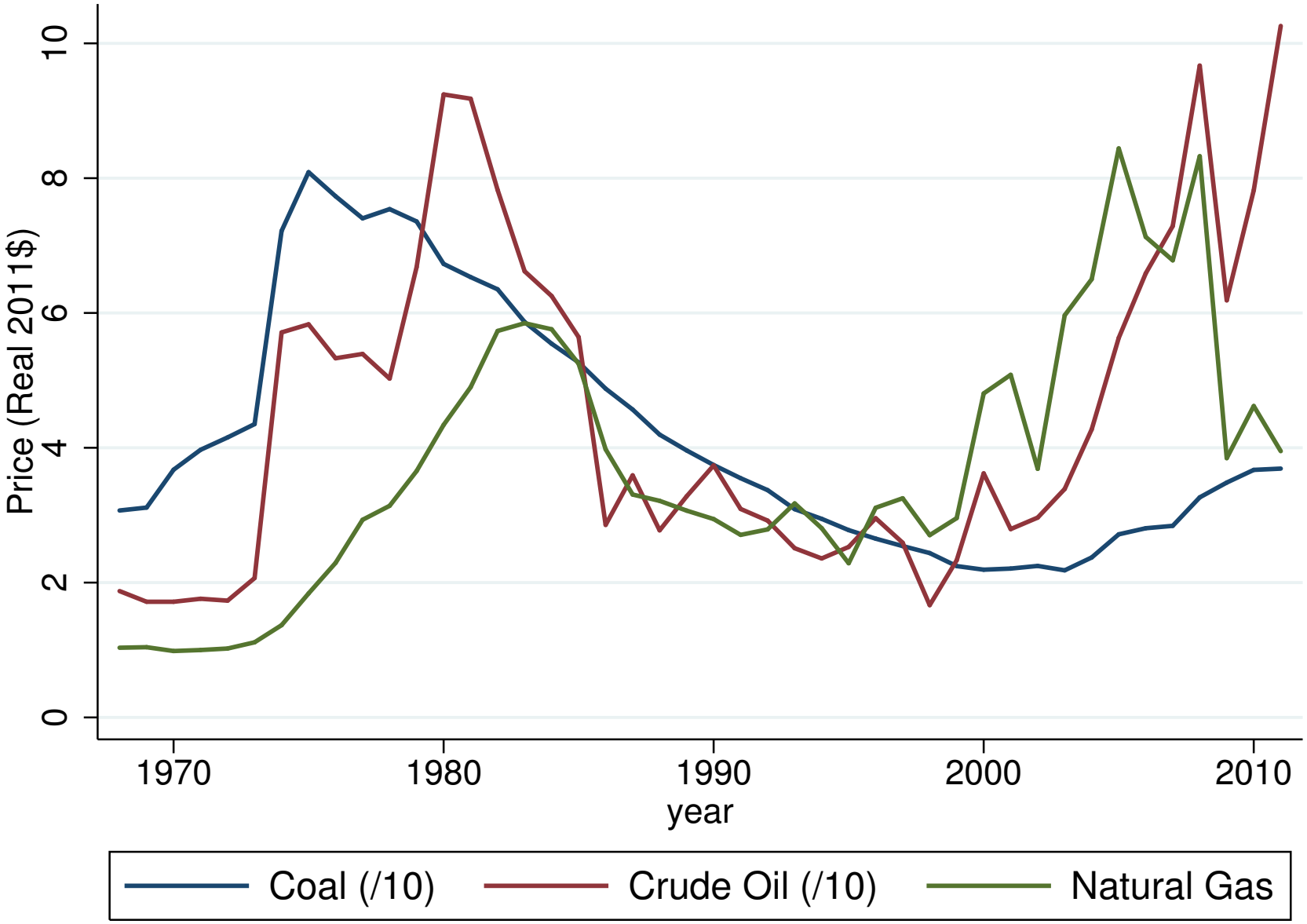
Effects of energy price shocks on marginal costs, markups, output prices

Research Design #1: Regions use different fuel mixes to generate electricity

Different Regions Use Different Fuels to Generate Electricity



National Variation in Fuel Prices Over Time



Effects of energy price shocks on marginal costs, markups, output prices

Research Design #1: Regions use different fuels to generate electricity

$$Y_{it} = \sum_{f \in \{\text{coal, gas, oil}\}} \left[\underbrace{\beta^f [E^f_{t,-s} \times \sigma^f_{s,t-k}]}_{\text{variables of interest}} \right] + X'_{it}\gamma + \eta_i + \epsilon_{it}$$

- $E^f_{t,-s}$ National (leave out mean) fuel prices
- $\sigma^f_{s,t-k}$ State generation shares, lagged k years

Effects of energy price shocks on marginal costs, markups, output prices

Research Design #2: Industries use different fuels for production.

Table – Allocation of Energy Input Expenditures across Fuels, by Industry

	Coal	Natural Gas	Fuel Oil	Electricity
Boxes	0.000	0.007	0.002	0.009
Bread	0.000	0.007	0.002	0.011
Cement	0.130	0.049	0.010	0.134
Concrete	0.000	0.002	0.011	0.007
Gasoline	0.000	0.014	0.817	0.007
Plywood	0.000	0.005	0.002	0.012

Source: ASM, MECS

Effects of energy price shocks on marginal costs, markups, output prices

Research Design #2: Industries use different fuels for production.

$$Y_{it} = \sum_{f \in \{\text{coal, gas, oil, electricity}\}} \left[\underbrace{\beta^f [E^f_{t,-s} \times \sigma^f_{j,t-k}]}_{\text{variables of interest}} \right] + X'_{it}\gamma + \eta_i + \epsilon_{it}$$

- $E^f_{t,-s}$ National (leave-out) mean fuel price for industrial consumers
- $\sigma^f_{j,t-k}$ Fuel share for industry j, lagged k years

Increases in Electricity Fuel Prices Increase Marginal Costs

Research Design #1

	Lag (t-0) (1)	Lag (t-2) (2)	Lag (t-5) (3)	Lag (t-0) (4)	Lag (t-2) (5)	Lag (t-5) (6)
Coal Price × Coal Share	0.092	0.156	-0.110	0.357	0.374	0.123
	(0.387)	(0.363)	(0.311)	(0.244)	(0.293)	(0.255)
Gas Price × Gas Share	0.779***	0.788***	0.866***	0.235***	0.225***	0.291***
	(0.175)	(0.140)	(0.191)	(0.086)	(0.084)	(0.061)
Oil Price × Oil Share	0.136	0.229	0.013	-0.070	0.047	-0.029
	(0.341)	(0.290)	(0.207)	(0.121)	(0.118)	(0.139)
Plant FE	X	X	X	X	X	X
Year FE	X	X	X			
State Trends	X	X	X	X	X	X
Region-Year FE				X	X	X
Product-Year FE				X	X	X

Notes: 6 regressions, 1 per column. Observation = plant-year. Energy data from EIA-SEDS, state-level. Marginal costs estimated using 3 factor (K, L, M), translog production function. S.E. clustered by state.

Interpretation [Column 4-6, Gas]: 1% increase in gas price ⇒ 0.291% increase in marginal costs for state with 100% gas generation share.

- Average gas generation share is 25% ⇒ 0.07% increase in marginal costs

Increases in Electricity Fuel Prices Increase Marginal Costs

Research Design #2

	(1) Lag (t-0)	(2) Lag (t-2)	(3) Lag (t-0)	(4) Lag (t-2)	(5) Lag (t-0)	(6) Lag (t-2)
	Marginal Costs		Unit Prices		Markups	
Coal Price × Coal Share	38.69***	66.79***	13.84***	31.06***	-24.85***	-35.73***
	(7.95)	(8.97)	(4.67)	(5.67)	(4.83)	(5.33)
Gas Price × Gas Share	136.44***	97.41***	75.80***	53.09**	-60.64**	-44.31**
	(29.32)	(40.44)	(22.71)	(23.65)	(25.59)	(19.87)
Oil Price × Oil Share	354.57***	419.99***	181.91***	247.12***	-172.66***	-172.87***
	(22.63)	(83.01)	(20.05)	(52.57)	(17.15)	(32.35)
Electricity Price × Share	-70.59**	112.69	-12.18	78.83	-58.41**	-33.85
	(32.25)	(116.56)	(19.10)	(68.15)	(23.64)	(46.82)
Plant FE	X	X	X	X	X	X
State Trends	X	X	X	X	X	X
Region-Year FE	X	X	X	X	X	X

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To What Extent are Plant-level Changes in MC Passed Through to Price?

Standard Pass-Through Regression: Price against Marginal Cost

$$p_{it} = \rho_{MC,\epsilon} mc_{it} + X'_{it}\gamma + \eta_i + \epsilon_{it}$$

Instrument mc_{it} with either of two research designs

- $\rho_{MC,\epsilon}$: marginal cost pass-through elasticity
- Why instrument? Measurement error; Policy-relevant LATE

Pass-Through Rate of Marginal Costs into Unit Prices: OLS

	(1)	(2)	(3)	(4)
Marginal Costs	0.598***	0.680***	0.598***	0.681***
	(0.018)	(0.033)	(0.018)	(0.032)
Plant FE	X	X	X	X
State Trends	X	X	X	X
Year FE	X			
Product-Year FE		X		X
Region-Year FE			X	X

Notes: This table presents regression coefficients from 4 separate regressions, one per column. An observation is a plant-year. The dependent variable is the plant-level unit-price, and the independent variable is plant-level marginal cost. Standard errors are in parentheses and are clustered by State. Regressions are weighted by Census sampling weights. ***,**,* denotes statistical significance at the 1, 5, and 10 percent levels, respectively. See text for details. Source: Census of Manufacturers, EIA-SEDS.

Marginal Cost Pass-Through: Research Design #1

Table – Pass-Through Rate of Marginal Costs into Unit Prices: Instrumental Variables

	(1) Lag (t-0)	(2) Lag (t-2)	(3) Lag (t-5)	(4) Lag (t-0)	(5) Lag (t-2)	(6) Lag (t-5)
	Panel A: Electricity Shift-Share Instrument					
Marginal Costs	0.628***	0.623***	0.625***	0.660***	0.654***	0.715***
	(0.031)	(0.031)	(0.029)	(0.099)	(0.088)	(0.086)
N	5892	5892	5892	5892	5892	5892
First Stage F-Statistic	9.53	14.33	6.99	8.89	3.95	12.09
Plant FE	X	X	X	X	X	X
Year FE	X	X	X			
State Trends	X	X	X	X	X	X
Product-Year FE				X	X	X
Region-Year FE				X	X	X

Notes: 6 regressions, 1 per column. Observation = plant-year. Energy data from EIA-SEDS, state-level. Markups estimated using 3 factor (K, L, M), translog production function. Standard errors clustered by state.

▸ OLS

Marginal Cost Pass-Through: Research Design #2

Table – Pass-Through Rate of Marginal Costs into Unit Prices: Instrumental Variables

	(1) Lag (t-0)	(2) Lag (t-2)	(3) Lag (t-0)	(4) Lag (t-2)
	Panel B: Fuel Shift-Share Instrument			
Marginal Costs	0.511***	0.514***	0.505***	0.508***
	(0.013)	(0.014)	(0.012)	(0.014)
N	5683	5683	5683	5683
First Stage F-Statistic	137.48	78.68	120.74	66.18
Plant FE	X	X	X	X
Year FE	X	X		
State Trends	X	X	X	X
Product-Year FE			X	X
Region-Year FE			X	X

Notes: 4 regressions, 1 per column. Observation = plant-year. Energy data from EIA-SEDS, state-level. Markups estimated using 3 factor (K, L, M), translog production function. Standard errors clustered by state.

▸ OLS

Pass-Through Elasticity by Industry - Instrumental Variables

Table – Pass-Through Rate of Marginal Costs into Unit Prices by Product: Instrumental Variables

	(1) Boxes	(2) Bread	(3) Cement	(4) Concrete	(5) Gasoline	(6) Plywood
	Panel A: Baseline - Electricity Price Instrument					
Marginal Costs	0.963***	0.681***	0.775***	0.711***	0.327**	0.692***
	(0.038)	(0.150)	(0.087)	(0.082)	(0.143)	(0.082)
Pass-Through Rate	1.42	0.82	1.78	0.80	0.36	1.02
First Stage F-statistic	23.41	1.67	49.29	23.36	2.43	38.55
	Panel B: Region-Year FE - Electricity Price Instrument					
Marginal Costs	0.992***	0.458***	0.801***	0.624***	0.242**	0.758***
	(0.057)	(0.172)	(0.100)	(0.066)	(0.111)	(0.068)
Pass-Through Rate	1.46	0.55	1.84	0.70	0.27	1.12
First Stage F-statistic	2.04	3.39	22.90	13.5	4.22	30.10

Notes: 12 regressions; one per column in each of the two panels. Each column represents a separate sample, where the sample is indicated in the column headings. Observation = plant-year. Dependent variable = plant-level unit-price. Independent variable = plant-level marginal cost. Marginal cost instrumented by national fuel prices for electricity generation × 5-year lagged electricity generation shares.

Demand Forms

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- Conclude

Incidence of Input Taxes under Imperfect Competition

Incidence of Input Tax under Imperfect Competition

$$I^{Oligopoly} = \frac{\rho}{\gamma - (1 - L \times \epsilon_D)\rho}$$
$$= \frac{\rho_{MC}}{1 - (1 - L \times \epsilon_D)\rho_{MC}}$$

Parameters:

- ρ_{MC} Marginal cost pass-through (Estimated above)
- $L = (P - MC)/MC$ Lerner Index (Estimated above)
- ϵ_D Demand elasticity (Methods from Foster, Haltiwanger, Syverson (2008))

Estimating Demand

Estimating Demand

Foster, Haltiwanger, Syverson (2008) estimate log-linear demand system

- Regress quantity on price, instrumenting price with a measure of TFP-Q
- Control for year FE + per capita county income

IV: TFP-Q

- TFP-Q a measure of producer technologies (physical production costs) $\Rightarrow$ strongly predict prices
- Unlikely to be correlated with short-run, plant-specific demand shocks

Physical Productivity Measure TFP-Q

- Productivity index, constant returns to scale with industry cost shares as output elasticities
- Deflate dollar-based inputs using NBER input price deflators (industry-year)
- Labor, capital, materials, and energy inputs

Welfare Incidence: Oligopoly

Rewrite Incidence as $\frac{dCS/d\tau}{dCS/d\tau + dPS/d\tau}$

- How much do consumers bear as % of loss [gain?] to producers+consumers?

Table – Incidence: Change in Consumer Surplus as Share of Change in Total Surplus

	(1) Boxes	(2) Bread	(3) Cement	(4) Concrete	(5) Gasoline	(6) Plywood
	Panel A: Incidence Components					
MC Pass-Through (ρ^F_{MC})	1.49	0.65	1.42	0.50	0.56	1.15
Demand Elasticity (ϵ_D)	3.24	2.42	1.82	5.53	8.70	1.39
Mean Lerner Index (L)	0.33	0.18	0.57	0.13	0.12	0.41
	Panel B: Consumer share of burden (by market structure)					
Oligopoly	0.63	0.43	0.46	0.58	0.31	0.64
	(0.03)	(0.17)	(0.09)	(0.07)	(0.22)	(0.18)

Bounding Incidence Between Perfect Competition and Monopoly

How to relax production function assumptions?

Bounding Exercise:

- Incidence from perfect competition and monopoly as bounds

$$I^{Competitive} = \frac{\rho}{\gamma - \rho} \qquad I^{Monopoly} = \frac{\rho}{\gamma}$$

- Only requires knowing pass-through rate and cost-shift rate
  - Pass-through rate we can estimate directly
  - Cost shift rate can be parameterized without having to estimate markups, marginal costs, and/or production functions

Bounding Incidence Between Perfect Competition and Monopoly

Bounding using marginal cost pass-through.

$$I^{Competitive} = \frac{\rho_{MC}}{1 - \rho_{MC}} \qquad I^{Monopoly} = \rho_{MC}$$

Table – Incidence: Change in Consumer Surplus as Share of Change in Total Surplus (Cont.)

	(1) Boxes	(2) Bread	(3) Cement	(4) Concrete	(5) Gasoline	(6) Plywood
	Panel A: Incidence Components					
MC Pass-Through (ρ^F_{MC})	1.49	0.65	1.42	0.50	0.56	1.15
Demand Elasticity (ϵ_D)	3.24	2.42	1.82	5.53	8.70	1.39
Mean Lerner Index (L)	0.33	0.18	0.57	0.13	0.12	0.41
	Panel B: Consumer share of burden (by market structure)					
Monopoly	0.59	0.41	0.64	0.44	0.24	0.52
	(0.02)	(0.17)	(0.17)	(0.05)	(0.12)	(0.16)
Perfect Competition	1.44	0.68	1.81	0.78	0.32	1.07
	(0.12)	(0.71)	(2.04)	(0.16)	(0.23)	(0.53)

Wrapping Up

Methodology to estimate incidence of cost shocks

Findings: Standard methods overstate share of burden for consumers.

- Reasons: incomplete pass-through, perfect competition

Ongoing Work: Optimal Pigouvian tax in concentrated industries.