ECON 8000/9000 Empirical Energy Econ

Topic 08: Pass-through and Incidence

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Outline

- Introduction
- Example 1: Barwick et al. (2023) AEA P&P
- Example 2: Pless & van Bentham (2019) AEJ:AE
- Example 3: Fabra & Reguant (2014) AER
- Example 4: Ganapati, Shapiro, & Walker (2020) AEJ:AE

1. Pass-through in Energy Econ

Typical questions

Big picture questions

- How does the pass-through of a consumer product depend on market structure and other factors?
- How do input cost shocks pass through to consumers?
- What's the distributional effect of taxes and subsidies on consumers?

Specific questions:

- How much do green subsidies (solar PV subsidy, EV subsidies, etc) pass through to consumers? Does the consumer fully capture the subsidy, or are they captured by the producers (think Tesla)?
- How much do cost shocks in the energy sector pass through to residential and industrial consumers?
- How much energy cost shocks in various sectors pass through to end-use consumers?
- Distributional effects?

2. Pass-through and Market Power

2.0 How to think about pass-through and incidence

Typical terminology and notations:

- Pass-thorough rate $\rho \equiv \frac{dp}{dt}$ or $\rho \equiv \frac{dp}{ds}$, with p being the price faced by the consumer
- Relative consumer incidence $I = \frac{\rho}{1-\rho}$
- Demand and supply elasticity in perfect competition: ε_d and ε_s
- Demand elasticity in monopoly and imperfect competition: ε

Pass-through rate will depend on ε(s) and market structure:

- The GOAT applied theory on this topic: **Weyl & Fabinger (2013) "Pass-through as an Economic Tool: Principals of Incidence under Imperfect Competition" JPE**
- WF (2013) reviews pass-through and incidence under perfect competition and monopoly
- WF (2013) develops a framework of pass-through for imperfect competition

2. Pass-through and Market Power

2.1 Market power = 0, perfect competition

$$\text{Pass-through } \rho = \frac{\varepsilon_s}{\varepsilon_s + \varepsilon_d} = \frac{1}{1 + \varepsilon_d/\varepsilon_s} \in (0, 1) \qquad \text{Consumer Incidence } I = \rho t \text{ or } \rho s \qquad (1)$$

- Here denote both elasticities as positive numbers
- If $\varepsilon_d = 0.5$ and $\varepsilon_s = 0.5$, then pass-through $\rho = 0.5 = 50\%$
- If subsidy $s = \$100$, then $I = \$50$
- Notation: While most people use I for incidence, WH (2013) use it to compare relative incidence $\rho/(1-\rho)$

Self-review: Small details for Eq(1):

- $Q^d(p) = Q^s(p - t)$ for price faced by consumer p and tax t
- Derivative on tax: $\frac{dQ^d(p)}{dp} \cdot \frac{dp}{dt} = \frac{dQ^s(p-t)}{d(p-t)} \frac{d(p-t)}{dt}$
- Given $\rho = \frac{dp}{dt}$, the above becomes $Q^{d\prime} \cdot \rho = Q^{s\prime} \cdot (1 - \rho)$, which yields $\rho = \frac{Q^{s\prime}}{Q^{s\prime} - Q^{d\prime}}$
- Normalize level changes into percentage changes: $\rho = \frac{\varepsilon_s}{\varepsilon_s + \varepsilon_d}$

2. Pass-through and Market Power

2.1 Market power = Max, monopoly

$$\text{Pass-through } \rho = \frac{\varepsilon}{1+\varepsilon} = 1 + \underbrace{\left(-\frac{1}{1+\varepsilon}\right)}_{\text{markup }\%} \qquad \text{Consumer Incidence } I = \rho t \text{ or } \rho s \tag{2}$$

- Eq(2) requires flat MC and constant demand elasticity
- If $\varepsilon = -1.5$ then pass-through $\rho = 3$ aka 300%
- If subsidy $s = \$100$, then $I = \$300$
- This is called **overshifting**

Self-review: Small details for Eq(2):

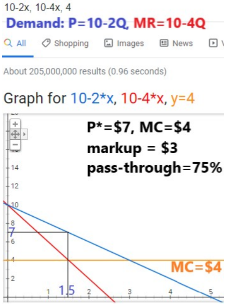
- Derive MR from $TR = P^d(Q) \cdot Q$ yields:
- $MR = \frac{dP}{dQ} Q + P = \frac{dP}{dQ}\frac{Q}{P} \cdot P + P = P(1 + \frac{1}{\varepsilon})$
- Given $MR = MC$, we have $P(1 + \frac{1}{\varepsilon}) = MC$, ergo, $P = \frac{\varepsilon}{1+\varepsilon} \cdot MC$
- Any cost shocks in MC due to t or s will change price by the pass-through rate of $\frac{\varepsilon}{1+\varepsilon}$

2. Pass-through and Market Power

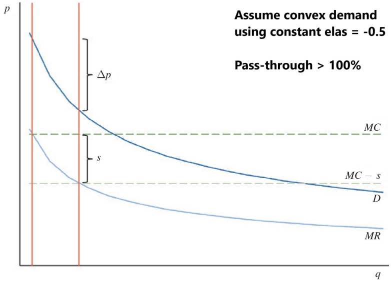
2.1 Market power = Max, monopoly, importance of demand curve curvature

- The example we just did implicitly assumed convex demand by assuming constant $\varepsilon = -1.5$
- If we do any undergrad-level monopoly problem with linear demand (left panel), you will find pass-through $< 100\%$

Left: Linear demand



Right: Convex demand



- Then how to improve Eq(2) to allow for various curvature?

2. Pass-through and Market Power

2.1 Market power = Max, monopoly, importance of ε_{ms}

WH (2013) relax constant MC and allow curvature in demand. The previous Eq(2) updates into the following which resembles some part of Eq(1)

$$\text{Pass-through (perf comp)} \quad \rho = \frac{1}{1 + \frac{\varepsilon_d}{\varepsilon_s}} \quad \text{consumer incidence } I = \rho t \text{ or } \rho s \tag{1}$$

$$\text{Pass-through (monopoly)} \quad \rho = \frac{1}{1 + \frac{\varepsilon_d - 1}{\varepsilon_s} + \frac{1}{\varepsilon_{ms}}} \quad \text{consumer incidence } I = \rho t \text{ or } \rho s \tag{2}$$

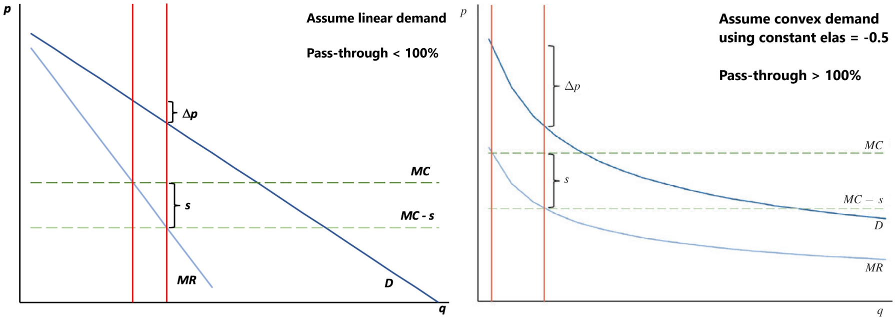
- ε_{ms} is the elasticity w.r.t inverse marginal surplus (the 2nd order curvature of log demand)
- If $\varepsilon_{ms} = 1$, linear demand; when $\varepsilon_{ms} > 1$, convex demand (e.g., constant elasticity demand)
- Suppose $\varepsilon_d = 0.5$, $\varepsilon_s = 1.5$, subsidy $s = \$100$, then
- pass-through under perfect comp $\rho = 0.75 = 75\%$, $I = \$75$
- pass-through under monopoly with $\varepsilon_{ms} = 1$, $\rho = 0.6 = 60\%$, $I = \$60$, no overshifting
- pass-through under monopoly with $\varepsilon_{ms} = 4$, $\rho = 1.09 = 109\%$, $I = \$109$, **overshifting**

2. Pass-through and Market Power

2.1 Market power = Max, monopoly, importance of ε_{ms}

Left: Linear demand ($\varepsilon_{ms} = 1$)
No over-shifting

Right: Convex demand ($\varepsilon_{ms} > 1$)
Overshifting



Source: Pless and van Bentham (2017)

2. Pass-through and Market Power

2.1 Market power $\in (0, Max)$, imperfect competition

WH (2013) further considers imperfect competition

Pass-through (perf comp)	$\rho = \dfrac{1}{1 + \frac{\varepsilon_d}{\varepsilon_s}}$	incidence $I = \rho t$ or ρs	(1)
Pass-through (monopoly)	$\rho = \dfrac{1}{1 + \frac{\varepsilon_d - 1}{\varepsilon_s} + \frac{1}{\varepsilon_{ms}}}$	incidence $I = \rho t$ or ρs	(2)
Pass-through (oligopoly)	$\rho = \dfrac{1}{1 + \frac{\theta}{\varepsilon_\theta} + \frac{\varepsilon_d - \theta}{\varepsilon_s} + \frac{\theta}{\varepsilon_{ms}}}$	incidence $I = \rho t$ or ρs	(3)

- ε_{ms} is the elasticity w.r.t inverse marginal surplus (the 2nd order curvature of log demand)
- $\theta \in (0, 1)$ is the conduct parameter. Think θ as (1 − aggregate diversion ratio)
- ε_θ as elasticity w.r.t. θ. For now, ignore the term $\theta/\varepsilon_\theta$ as it can be 0 in many models
- Suppose $\varepsilon_d = 0.5$, $\varepsilon_s = 0.5$, $s = \$100$, $\varepsilon_{ms} = 2$, $\theta = 0.95$, then
- pass-through under perfect comp $\rho = 0.5 = 50\%$, and $I = \$50$
- pass-through under monopoly is $\rho = 2 = 200\%$, and $I = \$200$, again **overshifting**
- pass-through under oligopoly is $\rho = 1.54 = 154\%$, and $I = \$154$, less **overshifting**

3. Typical Estimation Strategy

3.1 Reduced-form regressions

Given pass-through is $\rho = dp/dt$ or $\rho = dp/ds$, usually researchers estimate the following:

$$p_{it} = \beta s_{it} + \gamma \mathbf{X}_{it} + \phi_i + \phi_t + \varepsilon_{it} \tag{4}$$

- Panel data will be the best setting
- Key variable of interest usually are
  - subsidy amount s_{it} (as in this example)
  - tax amount t_{it}
  - cost shocks c_{it}
- Source of identification: quasi-random variation in s_{it}, t_{it}, or c_{it}
- Typical panel data estimators using Eq(4) or Eq(4)-esque specification:
  - DID, TWFE, Event Study, LP-DID, FD, etc.
- Other estimators and strategies:
  - RD: If subsidy or tax has a eligibility cutoff in some dimension (doesn't require panel data but panel data can help)
  - RDiT: Using subsidy and tax introduction/phase-out date as time cutoff
  - Shift-share IV: E.g., variation in energy mix spatially

3. Typical Estimation Strategy

3.1 Reduced-form regressions

Given pass-through is $\rho = dp/dt$ or $\rho = dp/ds$, usually researchers estimate the following:

$$p_{it} = \beta s_{it} + \gamma \mathbf{X}_{it} + \phi_i + \phi_t + \varepsilon_{it} \tag{4}$$

- Intepret key parameter of interest β
- Suppose yvar p_{it} is the post-subsidy price
  - If $\hat{\beta} = -0.6$, it suggests 60% pass-through, with producers absorbing 40% of s
  - If $\hat{\beta} = -1.6$, it suggests 160% pass-through (overshifting)
- Suppose yvar p_{it} is the list price
  - If $\hat{\beta} = 0.4$, it suggests 60% pass-through, with producers absorbing 40% of s
  - If $\hat{\beta} = -0.6$, it suggests 160% pass-through (overshifting)
- Eq(4) specifies p and s both in level and in the same unit
  - Doing so makes interpreting pass-through the most straightforward
  - Sometimes researchers specify Eq(4) in level-log, log-level, or log-log
  - Pass-through will be slightly less straightforward to interpret but do-able

3. Typical Estimation Strategy

3.2 Structural estimation

A two-step approach

- Step 1: Estimate a demand system and obtain demand elasticity
- Step 2: One can either (i) infer pass-through from demand elasticity or (ii) simulate counterfactual price given a subsidy shock to then see how price would change

3. Typical Estimation Strategy

3.2 Structural estimation

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A brief sneak peak of step 1 (we will cover this later in discrete-choice):

- Suppose one estimates a multinational logit demand for individual and product ij. The logit regression will aggregate into the following linear regression at product level j:

$$\ln s_{jt} - \ln s_{0t} = \beta p_{it} + \gamma \mathbf{X}_{jt} + \varepsilon_{it} \tag{5}$$

- Suppose you obtain a reliable price coefficient $\hat{\beta}$
- Then $\hat{\beta}$ would be used infer demand elasticity
- For each year t, abbreviate subscript t:
- The own-price elasticity of product j to itself is $\varepsilon_j = -\beta p_j(1 - s_j)$
- The average own-price elasticity of demand $\varepsilon = \frac{1}{J}\sum_j \varepsilon_j$

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Barwick, Kwon, Wang, and Zahur (2023) AEA P&P

"Pass-through of EV Subsidies: A Global Analysis"

Research Question: How do EV subsidies affect post-subsidy price for consumers?

TABLE 1—SUMMARY STATISTICS

Variable	Mean	SD
MSRP ($1,000) <-- yvar	61.88	37.85
Incentive ($1,000) <--xvar	3.21	3.62
Consumer subsidy ($1,000)	1.41	2.23
Tax incentive ($1,000)	1.81	3.64
Battery capacity (kWh)	25.82	21.43
Size (m^3)	12.67	2.53
Engine horsepower	195.42	97.78
Nonfinancial incentives	0.70	0.46

2 types of xvar (Consumer subsidy, Tax incentive)

Notes: Observations = 4,768. Each observation is an EV model sold in 1 of 13 countries over eight years.

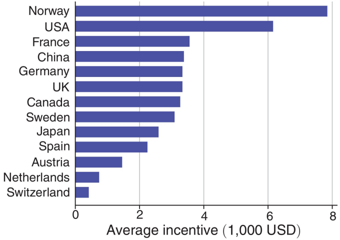

FIGURE 1. AVERAGE FINANCIAL INCENTIVE PER VEHICLE FROM CENTRAL GOVERNMENT, 2013–2020

- Time frame: 2013-2020
- Key variation in xvar: cross-product and cross-country variation in subsidy in various years
- Key yvar: MRSP + subsidy

Barwick et al. (2023) AEA P&P

Limitations (given their interest of doing a cross-country regression)

Table 1—Summary Statistics

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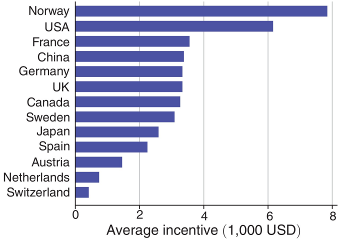

Figure 1. Average Financial Incentive per Vehicle from Central Government, 2013–2020

- Unit of observation: They cannot realistically observe EVs for all countries at a very fine level (trim or finer). They can at most observe at the vehicle model level.
- Sample: They cannot realistically observe non-EVs consistently across all 10+ countries. So sample includes only EVs. E.g., Accord ICE cannot be a control group for Accord PHEV

Barwick et al. (2023) AEA P&P

Estimation Equation

For product (vehicle model) j in country c year t, they estimate:

$$p_{jct} = \lambda incentive_{jct} + \beta \mathbf{X}_{jct} + \delta_{jc} + \delta_t + \varepsilon_{jct} \tag{1}$$

- Post-subsidy price $p = MRSP + incentive$
- Both yvar and xvar are in $1000
- Key parameter for pass-through: λ
- Controls X: battery capacity, vehicle size, horsepower, other non-financial incentives
- FEs: Model-by-country FE and year FE
- Identification:
  - Incentivizes are not quasi-random, so no causal claim
  - Q1: How do they try the best to do an apple-to-apple comparison?
    Hint: (i) data they include (ii) FEs they include

Barwick et al. (2023) AEA P&P

Results on post-subsidy price

Table 2—Pass-through Rates: Baseline

	Dependent variable: postsubsidy price			
	(1)	(2)	(3)	(4)
Incentive	−0.714	−0.798	−0.768	−0.772
	(0.112)	(0.088)	(0.090)	(0.086)
Battery capacity		−0.059	−0.057	−0.047
		(0.034)	(0.033)	(0.031)
Size		2.473	2.476	2.639
		(0.784)	(0.774)	(0.731)
Horsepower		0.111	0.110	0.110
		(0.016)	(0.016)	(0.016)
Nonfinancial incentives		−1.381	−1.430	−0.594
		(0.660)	(0.661)	(0.625)
Income			−0.134	−0.031
			(0.077)	(0.078)
Charging stations (log)				−3.306
				(0.699)
R^2, within	0.05	0.18	0.18	0.20
Observations	4245	4245	4245	4245

Note: All columns include country-by-model fixed effects and year fixed effects.

- Point estimate of $\hat{\lambda}$: from -0.71 to -0.80
- Pass-through rate is about: 71%-80%
- E.g., consider column (4), $\hat{\lambda} = -0.77$
  For each $1 subsidy:
  consumers see a lower price by $0.77
  producers raise MRSP by $0.23

Barwick et al. (2023) AEA P&P

Additional results on post-subsidy price

TABLE 3—PASS-THROUGH RATES BY GLOBAL REACH AND INCENTIVE TYPE

	Dependent variable: postsubsidy price			
	(1)	(2)	(3)	(4)
Incentive	−0.492			
	(0.120)			
Consumer subsidy			−0.630	−0.392
			(0.120)	(0.132)
Tax incentive			−0.949	−0.650
			(0.118)	(0.161)
Incentive × No. of sales countries	−0.037			−0.035
	(0.011)			(0.011)
Incentive × < 4 sales countries		−0.541		
		(0.115)		
Incentive × 4–11 sales countries		−0.836		
		(0.086)		
Incentive × > 11 sales countries		−0.972		
		(0.134)		
R^2, within	0.21	0.22	0.20	0.21
Observations	4245	4245	4245	4245

- Col (3): Greater pass-through from tax breaks
- Col (2): Greater pass-through if the model is sold in more countries

  → evidence for uniform pricing

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Pless & van Benthem (2019) AEJ:AE

"Pass-Through as a Test for Market Power: Solar Subsidies"

Research Question: How do solar PV subsidies in California pass through to the consumer?

- How does ρ differ between buying and leasing markets?
- If we find overshifting ($\rho > 1$), is this partially driven by a convex demand as theory (as in WH2013) predicts?

Key info:

- Time: 2010-2013
- Shock: California Solar Initiative (CSI) rebate program for solar PV
- Markets: Home-ownership (HO, buying) vs 3rd-party-ownership (TPO, leasing) market
- Data: CSI application data by California Distributed Generation Stat (CDGS) (link)
  - Transactional-level data for the HO market for each application ID
  - CDGS reports data for other programs as well

Pless & van Benthem (2019) AEJ:AE

Number of applicants + key yvar and xvar

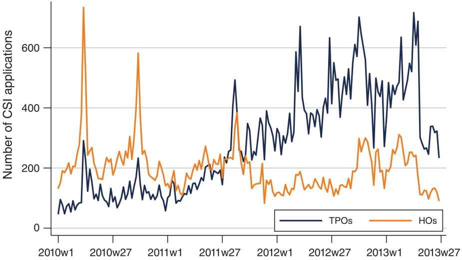


Figure 3. Trend in CSI Rebate Applications by Business Model in California, 2010–2013:II

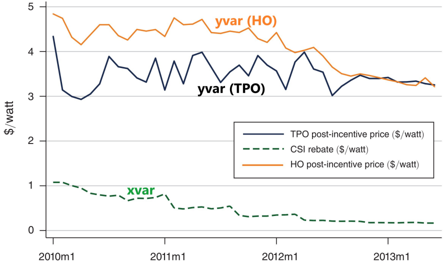


Figure 4. Post-incentive Price ($/Watt) Trends for TPO versus HO

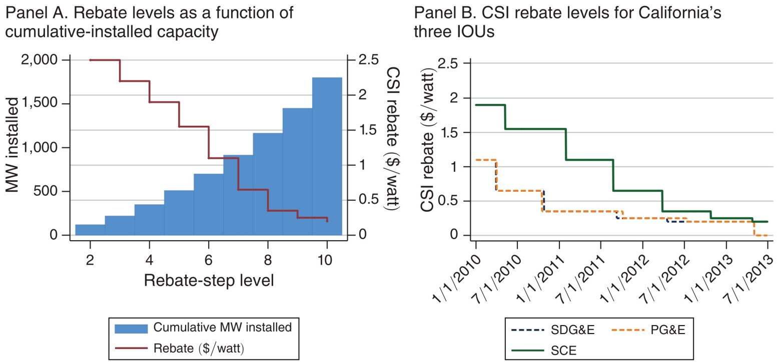
Left: Number of applicants

Right: Temporal variation in yvar + xvar

- Additional info: TPO market is more concentrated (fewer players)
- Subsidy is quite sizable compared to price

Key variation in xvar

(i) cross-sectional variation + (ii) temporal variation



Left: Cross-sectional variation by MW capacity

Right: Time-series variation in rebate price
Cross-sectional variation across 3 IOUs

- Q1. What generates (plausible) exogenous variation?

Measure yvar: post-subsidy price (in \$/watt)

For buyers (HO consumers)

Directly observable in CSI work data:

	A	B	C	D	E	F	G	H	I
1	**Application Number**	Program A	Program	Incentive Design	Incentive Type	Incentive Step	**Incentive Amount**	**Total Cost**	**Nameplate Rating**
2	SD-CSI-03095	CSE	Small Commercial (< 10 kW) and All Residential	\$1.55 per Watt EPBB	EPBB	Step 5	3446	0	2.816
3	SD-CSI-03355	CSE	Small Commercial (< 10 kW) and All Residential	98.184% @ \$1.55, 1.8	EPBB	98.184% @ Step	2424	22541.08	2
4	SD-CSI-05328	CSE	Small Commercial (< 10 kW) and All Residential	\$1.10 per Watt EPBB	EPBB	Step 6	7896	45871.44	8.64
5	SD-CSI-04105	CSE	Small Commercial (< 10 kW) and All Residential	\$1.10 per Watt EPBB	EPBB	Step 6	3049	20000	3.28
6	SD-CSI-04406	CSE	Small Commercial (< 10 kW) and All Residential	\$1.10 per Watt EPBB	EPBB	Step 6	7106	68716	8.2
7	SD-CSI-02337	CSE	Small Commercial (< 10 kW) and All Residential	\$1.90 per Watt EPBB	EPBB	Step 4	13047	60838	8.1
8	SD-CSI-05164	CSE	Small Commercial (< 10 kW) and All Residential	97.863% @ \$1.10, 2.1	EPBB	97.863% @ Step	8078	46189.95	8.64
9	SD-CSI-04392	CSE	Small Commercial (< 10 kW) and All Residential	\$1.10 per Watt EPBB	EPBB	Step 6	6516	48715.94	7.095
10	SD-CSI-04944	CSE	Small Commercial (< 10 kW) and All Residential	98.410% @ \$1.10, 1.5	EPBB	98.410% @ Step	7237	42131.55	7.68
11	SD-CSI-04122	CSE	Small Commercial (< 10 kW) and All Residential	91.948% @ \$1.55, 8.0	EPBB	91.948% @ Step	6606	38000	5.29
12	SD-CSI-04005	CSE	Small Commercial (< 10 kW) and All Residential	\$1.55 per Watt EPBB	EPBB	Step 5	20489	106840	15.4

- Post-subsidy price (in \$) = pre-subsidy price (called "total cost") - CSI subsidy - ITC subsidy
- CSI subsidy is observed
- ITC subsidy = 30% of (pre-subsidy price - CSI subsidy)
- Nameplate: solar PV capacity in KW
- Post-subsidy price (in \$/watt) = post-subsidy price (in \$) / (nameplate rating $\cdot 1000$)

Measure yvar: post-subsidy price (in $/watt)

For leasing customers (TPO consumers)

Pre-incentive cost is simply the net present value (NPV) of the upfront payment + yearly payments. You can also call it NPC

$$NPC_i = \text{upfront}_i + \sum_{y=1}^{t} \frac{\text{payment}_{iy}}{(1+d)^y}$$

- Assume discount rate $d = 7\%$
- Contracts are already adjusted by incentives
- Post-incentive price (in $) = NPC
- Post-subsidy price (in $/watt) = post-subsidy price (in $) / (nameplate rating $\cdot 1000$)

Pless & van Benthem (2019) AEJ:AE

Estimation equation

For consumer i

$$p_{it} = \alpha + \beta_1 rebate_{it} + \beta_2 rebate_{it} \cdot TPO_i + \beta_3 TPO_i + \mathbf{X}\phi \\ + \gamma_j + \delta_k + \varphi_u + \omega_z + \lambda_c + \mu_t + \varepsilon_{it}$$

- p_i: post-incentive price (in \$/watt)
- $rebate_{it}$: total subsidy (in \$/watt)
- Key parameter for pass-through: β_1 and β_2
- Controls X: age, education, income, and house value
- FEs and trends:
  - Solar PV attribute: manufacturer FE (γ_j), model FE (ω_z), installer company FE (λ_c)
  - Consumer location: county FE (δ_k), IOU FE (φ_u)
  - Time tremds: Week quadratic trends (μ_t)
    Q2. Why can't they use time FE?
- Identification:
  - Q3: What are they comparing?

Results: Pass-through $\hat{\rho}_{HO} = 78\%$ and $\hat{\rho}_{TPO} = 153\%$

Some overshifting in the TPO market

Table 2—Main Estimates: Pass-Through of Solar Subsidies

	Exclusion window			
	None (1)	+/−2 weeks (baseline) (2)	+/−4 weeks (3)	+/−6 weeks (4)
Panel A. Pooled regressions		**Baseline**		
Incentive	−0.756	−0.778	−0.746	−0.771
	(0.055)	(0.063)	(0.069)	(0.074)
Incentive × **1**[system = TPO]	−0.675	−0.750	−1.136	−1.199
	(0.210)	(0.234)	(0.268)	(0.293)
1[system = TPO]	−0.468	−0.378	0.095	0.142
	(0.172)	(0.203)	(0.246)	(0.281)
Observations	33,431	28,108	23,676	20,070
p-value: HO pass-through > −1	0.000	0.000	0.000	0.001
p-value: TPO pass-through < −1	0.021	0.013	0.001	0.001

	Ownership structure							
	HO	TPO	HO	TPO	HO	TPO	HO	TPO
Panel B. Separate regressions								
Incentive	−0.763	−1.229	−0.787	−1.333	−0.759	−1.768	−0.784	−1.904
	(0.054)	(0.302)	(0.063)	(0.351)	(0.069)	(0.433)	(0.074)	(0.510)
Observations	32,125	1,306	27,015	1,093	22,779	897	19,318	752
p-value: HO pass-through > −1	0.000		0.000		0.000		0.002	
p-value: TPO pass-through < −1		0.225		0.172		0.038		0.039

Note: The HO regressions in Panel B are replicable as they only need the CSI data.

Results: Pass-through $\hat{\rho}_{HO} = 78\%$ and $\hat{\rho}_{TPO} = 153\%$

Some overshifting in the TPO market

TABLE 2—MAIN ESTIMATES: PASS-THROUGH OF SOLAR SUBSIDIES

	Exclusion window			
	None (1)	+/−2 weeks (baseline) (2)	+/−4 weeks (3)	+/−6 weeks (4)
Panel A. Pooled regressions				
Incentive	−0.756	−0.778	−0.746	−0.771
	(0.055)	(0.063)	(0.069)	(0.074)
Incentive × $\mathbf{1}$[system = TPO]	−0.675	−0.750	−1.136	−1.199
	(0.210)	(0.234)	(0.268)	(0.293)
$\mathbf{1}$[system = TPO]	−0.468	−0.378	0.095	0.142
	(0.172)	(0.203)	(0.246)	(0.281)
Observations	33,431	28,108	23,676	20,070

- Potential reason 1: a more concentrated market has a conduct parameter θ closer to 1 as in WH(2013)'s language
- Potential reason 2: demand may be convex, aka a greater ε_{ms} in WH(2013)'s language
- It is to hard to speak to θ but maybe we can test convexity of the demand curve

A Simple Demand Estimation on Aggregate Data

Goal: examine if convex curvature is a potential mechanism for overshifting

Estimate aggregate demand at zipcode i by year t level:

$$q_{it} = \beta_1 p_{it} + \beta_2 p_{it}^2 + \theta \mathbf{X} + \delta_j + \tau_t + \varepsilon_{it}$$

- p: average post-incentive price (in \$/watt) in zipcode i
- Key parameter for pass-through: β_1 and β_2
- Controls X: age, education, income, and house value
- Literally all kinds of demand estimation require IV(s) for price:
  - Their choice of IVs are cost shifters: county level electrician/wiring wage rate and square from BLS

Demand Estimation Results

Run the same equation seperate for HO and TPO market

TABLE 6—DEMAND ESTIMATES FOR HO VS. TPO SYSTEMS

	OLS		IV	
	HO	TPO	HO	TPO
	(1)	(2)	(3)	(4)
Price	−0.261	−0.183	−0.534	−1.929
	(0.082)	(0.094)	(0.898)	(2.249)
Price^2	0.026	0.027	0.053	0.241
	(0.008)	(0.012)	(0.099)	(0.289)
Mean of dependent variable	0.461	0.518	0.461	0.518
First-stage F-statistic (price)			10.40	18.86
p-value (price)			0.000	0.000
First-stage F-statistic (price^2)			10.16	18.35
p-value (price^2)			0.000	0.000
Controls	X	X	X	X
County FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,196	5,196	5,196	5,196

- For both market: (i) downward-sloping demand $\hat{\beta}_1 < 0$ (ii) convex curve $\hat{\beta}_2 > 0$
- TPO consumers are (i) more elastic on average, (ii) less elastic when price is high
- TPO consumers' demand curve is more convex

Pless & van Benthem (2019) AEJ:AE

Piecing two sets of results together: Summary + Key Takeaway

Regression 1: A pass-through regression at consumer i level (the main regression):

$$p_{it} = \beta_1 rebate_{it} + \beta_2 rebate_{it} TPO_i + \text{Controls} + \text{FEs} + \varepsilon_{it}$$

- Pass-through $\hat{\rho}$: (i) $\hat{\beta}_1 = 78\%$ for HO, (ii) $\hat{\beta}_1 + \hat{\beta}_2 = 153\%$ for TPO
- Both pass-through are high, and TPO has overshifting

Regression 2: A simple demand estimation at zipcode i level separately for TPO and HO market

$$q_{it} = \beta_1 p_{it} + \beta_2 p_{it}^2 + \text{Controls} + \text{FEs} + \varepsilon_{it}$$

- Downward-sloping and convex demand curve ($\hat{\beta}_1 < 0$, $\hat{\beta}_2 > 0$)
- TPO demand curve is more convex

Pless & van Benthem (2019) AEJ:AE

Additional student questions

- Table 5: What does propensity score matching do here?
- Table 6: Imprecise estimate for β_2 regarding convexity
- Giffen?
- I was confused about the interaction between the CSI and the Federal ITC. Does the "more-than-complete" pass-through finding for lessees account for the fact that TPO installers also face a reduction in their tax-depreciation benefits (MACRS) when the CSI rebate increases?

Outline

- Introduction ✓
- Example 1: Barwick et al. (2023) AEA P&P ✓
- Example 2: Pless & van Bentham (2019) AEJ:AE ✓
- Example 3: Fabra & Reguant (2014) AER
- Example 4: Ganapati, Shapiro, & Walker (2020) AEJ:AE

Fabra & Reguant (2014) AER

"Pass-through of emission costs in electricity markets"

Research Question: How does emission cost (from environmental regulation) pass through to wholesale electricity price?

- If the electricity market is perfectly competitive, given (almost) inelastic demand, we shall expect 100% pass-through
- But number of firms are limited, and many past studies in other context found less than 50% or even lower pass-through
- If any future policies change generate electricity (costly regulation or subsidy), policymarkers should be informed how much costs or subsidies would be pass to the end-use consumers

Key idea: Use cost shocks in emission under EU ETS as a variation

- Time frame: 2004 - 2006; Market: Spain electricity market
- EU Emission Trading System (ETS) is cap-n-trade system
- Source of cost shock: time-varying equilibrium permit price of emitting pollution per ton

Fabra & Reguant (2014) AER

Sub Research Questions

Research Question: How does emission cost (from environmental regulation) pass through to wholesale electricity price?

- RQ1: What is the pass-through ρ from emission costs to **equilibrium electricity price**?
- RQ2: How does variation in emission cost affect firm's **price supplied**

Why these two sub-RQs?

- RQ1 is the main RQ. The purpose is to estimate the pass-through
  - Eventually, they find a relatively high pass-through (close to 1)
  - RQ2's purpose is to explore the mechanism that drives a high pass-through
- Given RQ1 an RQ2 serve different purposes
  - RQ1 will be estimated at the market level
  - RQ2 will be estimated at the firm level

History of EU ETS + Temporal Variation

Allowance/Permit Market: 2005 to 2024

- A huge market now
- This paper: 2004-2006
- A brief collapse in 2007-2008
- They set too high the "cap"
- Credit not transferrable between phase 1 (pre 2008) and phase 2 (post 2008)

RQ1: Suggestive Evidence of Some Pass-through

Temporal correlation between yvar and xvar (2004-2006)

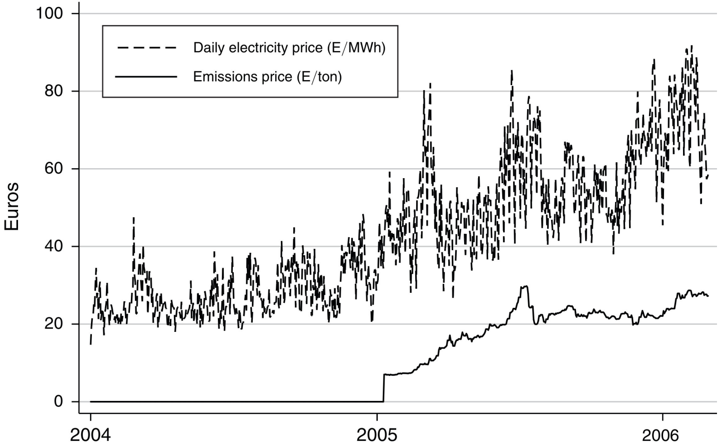


Figure 1. Evolution of the ETS Carbon Price and the Spanish Wholesale Electricity Price

RQ1: How to construct xvar? Key variation?

(i) temporal allowance price variation (ii) emission intensity by hour

Left: Allowance price τ_t (euro/ton) (varying by day)

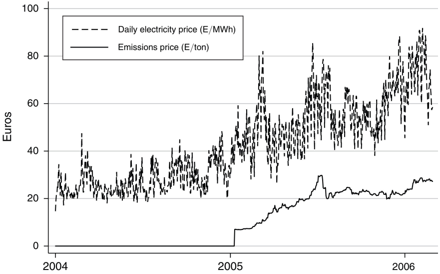


FIGURE 1. EVOLUTION OF THE ETS CARBON PRICE AND THE SPANISH WHOLESALE ELECTRICITY PRICE

Right: Emission intensity e_{th} (ton/MWh) (varying by hour)

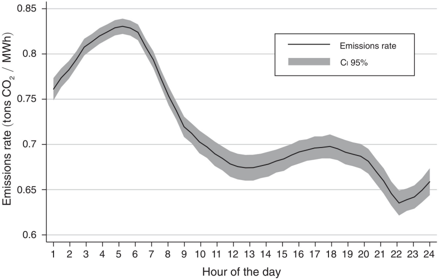


FIGURE 2. AVERAGE MARGINAL EMISSIONS RATE ACROSS THE DAY

- Multiply allowance price with emission rate, we obtain $\tau_t e_{th}$: euro per MWh
- Interpret $\tau_t e_{th}$: marginal cost to emit per MWh of electricity generation
- Q2: Do you know why the emission rate e_{th} vary by hour of a day?
- Q3: How does $\tau_t e_{th}$ vary now?

RQ1: Estimate pass-through at the market level

Estimation equation on equilibrium price

For day t hour h, they estimate:

$$p_{th} = \rho \tau_t e_{th} + \beta \mathbf{X}_{th} + \phi_t + \phi_h + \varepsilon_{th} \quad (1)$$

- p_{th}: electricity price in euro/MWh
- $\tau_t e_{th}$: marginal cost in euro/MWh for electricity generation
- Key parameter for pass-through: ρ
- IV for $\tau_t e_{th}$: use τ_t
- Controls X:
  - Coal price, gas price, oil price
  - Weather control: temperature
  - Wind generation potential: wind speed
- FEs: month FE, day-of-week FE, hour-of-day FE
- Identification:
  - Q4: What are they comparing?

RQ1: Estimate pass-through at the market level

Key results: 83-86% pass-through

TABLE 1—COST PASS-THROUGH REGRESSION RESULTS

	(1)	(2)	(3)	(4)	(5)
Mg. emissions costs (ρ)	0.862	0.860	0.835	0.829	0.848
	(0.181)	(0.182)	(0.173)	(0.172)	(0.168)
Temperature	−0.231		−0.204		
	(0.060)		(0.057)		
Maximum temperature	0.137		0.112		
	(0.050)		(0.047)		
Wind speed	−2.086	−2.171	−2.089	−2.191	−2.238
	(0.354)	(0.361)	(0.333)	(0.337)	(0.329)
Wind speed squared	0.055	0.066	0.054	0.067	0.068
	(0.025)	(0.025)	(0.023)	(0.023)	(0.023)
Coal	57.477	45.548	57.496	45.469	
	(4.035)	(4.364)	(3.885)	(4.164)	
Gas	5.638	3.589	5.604	3.563	
	(0.407)	(0.405)	(0.391)	(0.387)	
Brent	−2.896	−1.685	−2.938	−1.778	
	(0.881)	(0.985)	(0.834)	(0.930)	
F-test	124.8	114.0	129.9	119.3	118.3
Month × temp, maxtemp	No	Yes	No	Yes	Yes
Month × hour FE	No	No	Yes	Yes	Yes
Hour × input	No	No	No	No	Yes

RQ1: Estimate pass-through at the market level

Results: Greater pass-through for off-peak cost shocks

TABLE 2—COST PASS-THROUGH REGRESSION RESULTS: PEAK VERSUS OFF-PEAK

		(1)	(2)	(3)	(4)	(5)
Mg. emissions costs—peak	8am-8pm	1.085	1.083	1.055	1.051	1.107
		(0.185)	(0.185)	(0.178)	(0.177)	(0.175)
Mg. emissions costs—off-peak	evening +	0.635	0.633	0.608	0.603	0.496
	zombie hour	(0.170)	(0.170)	(0.164)	(0.163)	(0.164)
Month $\times$ temp, maxtemp		No	Yes	No	Yes	Yes
Month $\times$ hour FE		No	No	Yes	Yes	Yes
Hour $\times$ input		No	No	No	No	Yes

- Typical explanation: fixed cost problem
- Costly ramp-up and ramp-down for coal-fired plants that tend to operate in the off-peak hours

RQ1: Estimate pass-through at the market level

Discussion of Eq(1) estimates

RQ1: A pass-through regression on the equilibrium price

$$p_{th} = \rho \tau_t e_{th} + \beta \mathbf{X}_{th} + \phi_t + \phi_h + \varepsilon_{th} \tag{1}$$

- Main estismates of $\hat{\rho} \approx 0.85$
- $\Rightarrow$ 85% pass-through from cost shocks to the **equilibrium price**
- Until recent literature (studies post 2015), most studies don't find high pass-through
- Why do we get a high pass-through?

RQ2: Can we examine how emission costs affect the firm's pricing decision (**price supplied** p^s)?

- Are firms raising bidding prices (price supplied) as emission costs go up?
- Maybe estimate something like: "$p^s_{ith} = \gamma mc_{it} + \text{controls and FEs} + \varepsilon_{ith}$ "
- Then see what we learn about γ?
- Need to estimate this at firm level

RQ2: How do cost shocks affect price supplied?

Set up + parametrization

The basic idea: the price-setting decision is $p^s = mc + markup$. Write mc into two parts:

$$p^s = mc^{emiss} + mc^{input} + markup$$

- mc^{emiss} is MC from paying for emission allowance on the ETC market
- mc^{input} is MC from burning fuel

Parameterize the above price-setting equation

$$p^s = \gamma mc^{emiss} + \beta mc^{input} + \theta markup + \varepsilon$$

- If $\gamma = 1$, then emission cost is cooked into bidding price 1-for-1
- Next, I will add subscripts and explain key yvar and xvar

RQ2: Price-supplied at firm and unit level

Measure y and key xvar (mc from emission costs)

For firm i's electricity generating unit j in hour h and day t:

$$p^s = \gamma mc^{emiss} + \beta mc^{input} + \theta markup + \varepsilon$$

$$b_{ijth} = \gamma mc_{jt}^{emiss} + \beta mc_{jt}^{input} + \theta markup_{ijth}^{realized} + \varepsilon_{ijth} \qquad (5)$$

- b_{ijth}: bidding price as price supplied (Euro/MWh)
- mc_{jt}^{emiss}: will be cost shocks from buying emission allowance (Euro/MWh)
  - Each unit j has its own emission control technology and ergo varying emission intensity e_j (in Ton/MWh)
  - Daily emission price (Euro per ton): τ_t
  - MC by unit and hour: $mc_{jt}^{emiss} = \tau_t e_j$
  - Q5: Looking back to Q4, do you how what e_{th} vary through out the day?
  - Q6: How does identification work when using $\tau_t e_j$?
  - Q7: If you find $\hat{\gamma} = 1$, it means?

RQ2: Price-supplied at firm and unit level

Measure additional mc of using fuel for power generation

For firm i's electricity generating unit j in hour h and day t:

$$b_{ijth} = \gamma mc_{jt}^{emiss} + \beta mc_{jt}^{input} + \theta markup_{ijth}^{realized} + \varepsilon_{ijth} \tag{5}$$

- b_{ijth}: bidding price as price supplied (Euro/MWh)
- $mc_{jt}^{emiss} = \tau_h e_j$: mc of emission costs (Euro/MWh)
- mc_{jt}^{input}: mc from burning fuel (Euro/MWh)
  - A feature in electricity market: mc^{input} can be directly constructed
  - Each unit j has its own energy efficiency called heat rate r_j (in Btu/MWh)
  - Each fuel has its own heat content h_j (Btu/ton)
  - Each fuel will have its own price fp_t (in Euro/ton)
  - Put all 3 together for MC: $mc_{jt}^{input} = fp_t \frac{1}{h_j} r_j$
  - Q8: What if a unit runs on both coal and natural gas?

RQ2: Price-supplied at firm and unit level

Measure realized markup in Eq(5)

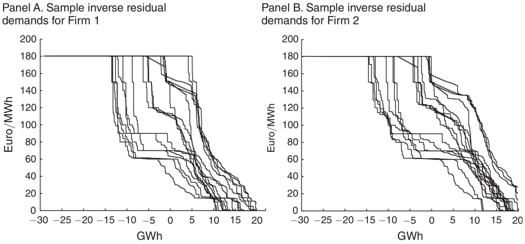
For firm i's electricity generating unit j in hour h and day t:

$$b_{ijth} = \gamma mc_{jt}^{emiss} + \beta mc_{jt}^{input} + \theta markup_{ijth}^{realized} + \varepsilon_{ijth} \tag{5}$$

Measure markup according Eq(4):

$$markup_{it}^{realized} = \left| \frac{\partial p_{it}}{\partial q_{it}} \right| q_{it}^{N} \tag{4}$$

- Part 1: Measure $\frac{\partial p_{it}}{\partial q_{it}}$ directly using the slope of the realized residual demand curve from bidding data. Two examples here.



- Part 2: Measure q_{it}^{N} using hourly production (MWh), net-out other contracts

Explanation: Why using $\left|\frac{\partial p_{it}}{\partial q_{it}}\right| q_{it}^N$ for markup?

Case 1: Monopoly

- Profit-maximization problem: $\pi = p^d(q)q - cq$
- FOC gives: $\frac{\partial p}{\partial q} q + p - c = 0$.
- Re-arrange yields: $p = c + \frac{\partial p}{\partial q} q$, with $markup = \frac{\partial p}{\partial q} q$

Case 2: Oligopoly with 3 firms in Cournot

- Profit-maximization for firm 1: $\pi_1 = p_1^d(q_1; q_2, q_3)q_1 - c_1 q_1$
- FOC gives: $\frac{\partial p(q_1; q_2, q_3)}{\partial q_1} q_1 + p_1 - c_1 = 0$
- Re-arrange: $p_1 = c_1 + \frac{\partial p(q_1; q_2, q_3)}{\partial q_1} q_1$, with $markup_1 = \frac{\partial p(q_1; q_2, q_3)}{\partial q_1} q_1$

Case 3: Oligopoly with N firms as in this paper

- Similarly, pofit for firm 1: $\pi_1 = p_i^d(q_1; q_2, q_3 \cdots q_N)q_1 - c_1 q_1$
- FOC yields $markup_1 = \frac{\partial p(q_1; q_2, q_3 \cdots qN)}{\partial q_1} q_1$, or simply $markup_1 = \frac{\partial p_1}{\partial q_1} q_1$
- Simply, measure markup = slope of residual demand × quantity (MWh) electricity sold

RQ2: How do cost shocks affect price supplied?

Results

For firm i's electricity generating unit j in hour h and day t:

$$b_{ijth} = \gamma mc_{jt}^{emiss} + \beta mc_{jt}^{input} + \theta markup_{ijth}^{realized} + \varepsilon_{ijth} \quad (5)$$

- b_{ijth}: bidding price as price supplied
- $mc_{jt}^{emiss} = \tau_h e_j$: mc of emission costs
- Point estimate: We find $\hat{\gamma}$ all around 1
- Consider SE, we also cannot reject $H_0 : \gamma = 1$

TABLE 3—TEST BASED ON STRUCTURAL EQUATIONS

	All	Firm 1	Firm 2	Firm 3	Firm 4
Panel A. Emissions cost (γ)					
(1) No FE	0.939	0.925	0.998	1.117	0.806
	(0.070)	(0.039)	(0.032)	(0.039)	(0.073)
(2) Unit FE	0.971	0.947	0.963	1.062	0.803
	(0.034)	(0.031)	(0.039)	(0.046)	(0.102)
(3) Unit FE + season	0.957	0.959	0.963	1.008	0.784
	(0.034)	(0.028)	(0.027)	(0.053)	(0.085)
(4) Spec.3 + markup (IV)	0.959	1.036	0.962	1.013	0.834
	(0.062)	(0.058)	(0.024)	(0.197)	(0.101)

Fabra & Reguant (2014) AER

Piecing two sets of results together: Summary + Key Takeaway

Regression 1: A pass-through regression on the equilibrium price (the main regression):

$$p_{th} = \rho \tau_t e_{th} + \beta \mathbf{X}_{th} + \phi_t + \phi_h + \varepsilon_{th} \tag{1}$$

- Pass-through $\hat{\rho}$ around 85%, high pass-through rate

Regression 2: A firm's strategic pricing regression (on price supplied)

$$b_{ijth} = \gamma mc_{jt}^{emiss} + \beta mc_{jt}^{input} + \theta markup_{ijth}^{realized} + \varepsilon_{ijth} \tag{5}$$

- Point estimate: We find $\hat{\gamma}$ all around 1
- We also cannot reject $H_0 : \gamma = 1$
- Interpretation: Firms price all cost shocks into 100% of the bidding price
- After accounting for demand, not just supply (as in Eq(5)), the consumer ends up bearing 85% of cost shocks from emission costs in the equilibrium

Outline

- Introduction ✓
- Example 1: Barwick et al. (2023) AEA P&P ✓
- Example 2: Pless & van Bentham (2019) AEJ:AE ✓
- Example 3: Fabra & Reguant (2014) AER ✓
- Example 4: Ganapati, Shapiro, & Walker (2020) AEJ:AE

Ganapati, Sharpiro, and Walker (2020) AEJ:AE

"Energy Cost Pass-Through in US Manufacturing"

Research Question: How does energy input cost (from electricity and fuel use) pass through to consumers from 1972 to 1997?

- Usual strategies:
  Estimate energy cost pass-through ρ using dp/dt and dp/ds
  However, in manufacturing and 1972-1997, not much variation in t nor s in energy inputs
- Strategy: Estimate ρ using dp/dc there are energy input cost variation across locations, industries, over time
- Implication: We will learn what the pass-through from a potential tax t or subsidy s would be if future policies directly affect energy input cost

Three sub-RQ:

- Time: 1972-1997
- Six industries in manufacturing that produce homogeneous goods: boxes, bread, cement, concrete, gasoline, plywood

Ganapati, Shapiro, and Walker (2020) AEJ:AE

Sub Research Questions

Research Question: How does energy input cost (from electricity and fuel use) pass through to consumers from 1972 to 1997?

- RQ1: What is the pass-through from MC to P driven by energy cost variation?
- RQ2: Given $\hat{\rho}$ estimated from RQ1, what is implied Lerner Index and demand elasticity?
- RQ3: Given RQ1 and RQ2, what would be the relative consumer incidence under various market structure, i.e., perfect competition, monopoly, or the observed oligopoly?

Our focus:

- We will focus on cover RQ1

RQ1: Pass-through from MC to price

Estimation strategy

For plant i in state s in year t, the authors estimate the trans-log equations:

$$p_{ist} = \rho_{elas} mc_{it} + \gamma \mathbf{X}_{nst} + \eta_i + \pi_t + \varepsilon_{ijth} \quad (6)$$

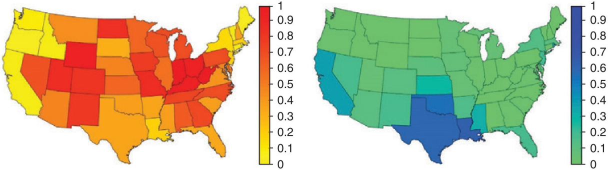
- p: log price
- mc: log MC
- ρ_{elas}: how 1% increase in MC manifests into % changes in price
  - We can easily convert it back to the pass-through that we usually use
  - $\rho = \rho_{elas} \cdot \frac{P}{MC}$
- Key FEs: plant FE, year FE, state trend
- Two issues:
  - 1. How to measure MC ⇒ For now, pretend this is already constructed
  - 2. MC is endogenous ⇒ Use shift-share IVs
  - Q1: Why is MC endogenous?

Baseline IVs for mc_{it}: Electricity Shift-share IVs

Each plant i is located in a state that uses 3 fuels for electricity: coal, gas, oil

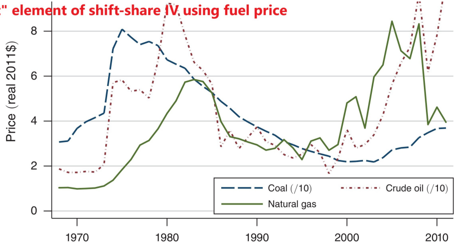
1. "share" element of shift-share IV

Panel A. Coal | Panel B. Natural gas



- Share σ_{st}: expenditure share of a fuel in power generation e.g., coal share in 1990
  $\sigma_{SC,1990} \approx 0.4$
  $\sigma_{IL,1990} \approx 0.9$
  Also, can use lagged share

2. "shift" element of shift-share IV using fuel price



- Shift $e_{-s,t}$: national log fuel price minus state log fuel price

Robustness IVs: Energy-input Shift-share IVs

Each plant i belongs to an industry n that uses 4 energy inputs: coal, gas, oil, elec

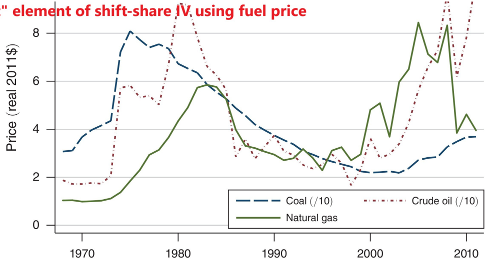
1. Alternative "share" element of shift-share IV

TABLE 1—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

- Share σ_{nt}: expenditure share of an energy input
  e.g., coal share in 1990
  $\sigma_{cement,1990}$ is high
  $\sigma_{boxes,1990}$ is low
  Also, can use lagged share

2. "shift" element of shift-share IV using fuel price



- Shift $e_{-n,t}$: national log price for energy input minus industrial-level log price

RQ1: Pass-through from MC to price

Summary of Shift-share IVs for MC

For plant i in state s in year t, the authors estimate the trans-log equations:

$$p_{ist} = \rho_{elas} mc_{it} + \gamma \mathbf{X}_{nst} + \eta_i + \pi_t + \varepsilon_{ijth} \quad (6)$$

- Baseline shift-share IVs: 3 IVs based on how electricity is generated in each state over time
- For each fuel, $z_{st} = \sigma_{s,t} \cdot e_{-s,t}$
- "Share" $\sigma_{s,t}$ = expenditure share of a fuel out of all fuel costs used in power generation in state s year t
  - $\sigma_{s,t}$ can be modified to lagged share $\sigma_{s,t-2}$, $\sigma_{s,t-5}$ etc.
  - Most variation in $\sigma_{s,t}$ is cross-sectional variation
- "Shift" $e_{-s,t}$ is national log fuel price - state log fuel price
- Construct z_{st} separately for coal, natural gas, and oil

OLS results of IVs' Effect on MC, P, and Markup

TABLE 3—RELATIONSHIP BETWEEN MARGINA

	Lag $(t-0)$ (1)
Panel A. Marginal costs	
Coal price × coal share	0.092
	(0.387)
Gas price × gas share	0.779
	(0.175)
Oil price × oil share	0.136
	(0.341)
Panel B. Unit prices	
Coal price × coal share	0.081
	(0.259)
Gas price × gas share	0.491
	(0.109)
Oil price × oil share	0.101
	(0.181)
Panel C. Markups	
Coal price × coal share	−0.012
	(0.220)
Gas price × gas share	−0.288
	(0.080)
Oil price × oil share	−0.035
	(0.181)
Observations	5,892
Plant fixed effects	X
Year fixed effects	X
State trends	X

- Reasonable effects from IV on 3 outcomes
- Most useful variation is from the natural gas shift-share IV
- Suggestive evidence of less than full pass-through on average

RQ1: Pass-through estimates: $\hat{\rho}_{elas}$ and $\hat{\rho}$

Pass-through $\hat{\rho}$ ranges from 36% to 178% (some overshifting)

TABLE 6—PASS-THROUGH RATE OF MARGINAL COSTS INTO UNIT PRICES: INSTRUMENTAL VARIABLES

ρ for dln(p)/dln(mc)

	Lag (t – 0) (1)	Lag (t – 2) (2)	Lag (t – 5) (3)	Lag (t – 0) (4)	Lag (t – 2) (5)	Lag (t – 5) (6)
Panel A. Electricity shift-share instrument						
Marginal Costs	0.628 (0.031)	0.623 (0.031)	0.625 (0.029)	0.660 (0.099)	0.654 (0.088)	0.715 (0.086)
Observations	5,892	5,892	5,892	5,892	5,892	5,892
First-stage *F*-statistic	9.53	14.33	6.99	8.89	3.95	12.09
Plant fixed effects	X	X	X	X	X	X
Year fixed effects	X	X	X			
State trends	X	X	X	X	X	X
Product-year fixed effects				X	X	X
Region-year fixed effects				X	X	X

TABLE 7—PASS-THROUGH RATE OF MARGINAL COSTS INTO UNIT PRICES BY PRODUCT: INSTRUMENTAL VARIABLES

	Boxes (1)	Bread (2)	Cement (3)	Concrete (4)	Gasoline (5)	Plywood (6)
Panel A. Baseline—electricity price instrument						
Marginal costs **ρ for dln(p)/dln(mc)**	0.963 (0.038)	0.681 (0.150)	0.775 (0.087)	0.711 (0.082)	0.327 (0.143)	0.692 (0.082)
Observations	1,414	308	293	3,369	345	163
Pass-through rate **ρ = dp/dmc --->**	1.42	0.82	1.78	0.80	0.36	1.02

Additional Details: How are mc_{it} constructed?

Output price p_{it} can be observed, but not MC

When estimating Eq(6), the key xvar mc_{it} is not observed...

- Without measuring mc_{it}, we cannot run Eq(6)...
- MC not observed is a common feature to nearly all industries
- The only exception is power sector, when fuel use data are collected by authorities
- In most scenario, MC is infered from firm's FOC

One way to describe MC is that $P = MC \cdot \mu$ where μ is the multiplicative markup

- So if we can estimate the multiplicative markup μ, we can construct $mc_{it} = p_{it}/\mu_{it}$
- How to measure the markup ratio μ_{it} then?

Additional Details: How are mc_{it} constructed?

Use CMP for a plant to measure μ_{it} first

Suppose a plant generates output according to the production function $Q = Q(V, D, \Omega)$

- Two types of inputs: variable input V, dynamic input D (including K)
- Energy input is part of V
- Productivity or technology level is Ω
- Price for D is P^v, and price for capital is R

Lagrangian for cost minimization problem (CMP):

$$\mathcal{L} = P^v V + RK + \lambda[Q - Q(V, D, \Omega)]$$

FOC with respect to V:

$$P^v + \lambda \cdot [-\frac{\partial Q}{\partial V}] = 0$$

$$P^v = \lambda \cdot \frac{\partial Q}{\partial V} \qquad \text{(FOC-v)}$$

- This is the classic FOC that factor price = shadow cost $\lambda \times$ marginal product MP_V
- Recall that shadow cost is also the MC by Envelope Theory (because $\lambda = dTC/dQ$)
- If we can measure P/λ using the (FOC-v), then we will be able to compute μ_{it}

Additional Details: How are mc_{it} constructed?

Use CMP for a plant to measure μ_{it} first

Lagrangian for cost minimization problem (CMP):

$$\mathcal{L} = P^v V + RK + \lambda[Q - Q(V, D, \Omega)]$$

$$\text{FOC-v}: \quad P^v = \lambda \cdot \frac{\partial Q}{\partial V}$$

$$\text{Create } \frac{P}{\lambda}: \quad \frac{P}{\lambda} = \frac{P}{P^v} \cdot \frac{\partial Q}{\partial V}$$

$$\text{Rewrite it as}: \quad \mu = \frac{P}{P^v} \cdot \frac{\partial Q}{\partial V} \cdot \frac{V}{Q} \cdot \frac{Q}{V}$$

$$\mu = \left[\frac{\partial Q}{\partial V} \cdot \frac{V}{Q}\right] \cdot \left[\frac{P}{P^v} \cdot \frac{Q}{V}\right]$$

$$\mu = \underbrace{\left[\frac{\partial Q}{\partial V} \cdot \frac{V}{Q}\right]}_{\text{output elasticity}} \cdot \underbrace{\left[\frac{P^v V}{PQ}\right]^{-1}}_{\text{revenue share}}$$

- First term: output elasticity can be estimated using the trans-log version of Cobb-Douglas
- Second term: directly measurable e.g., a plant's coal cost may be 5% compared to its revenue
- After μ is constructed, $mc_{it} = p_{it}/\mu_{it}$ and we can estimate Eq(6)