Internalization and Passthrough of Emission Costs in Electricity Markets

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Two Important Concepts

- *Internalization rate:* Do firms fully internalize emissions costs?
  - Important to ensure externality is incorporated in behavior.
  - Opportunity costs of using free permits.
- *Pass-through rate:* How do prices reflect cost increases?
  - Heterogenous cost shock: price pass-through vs. cost pass-through.
  - Supply and demand channels.

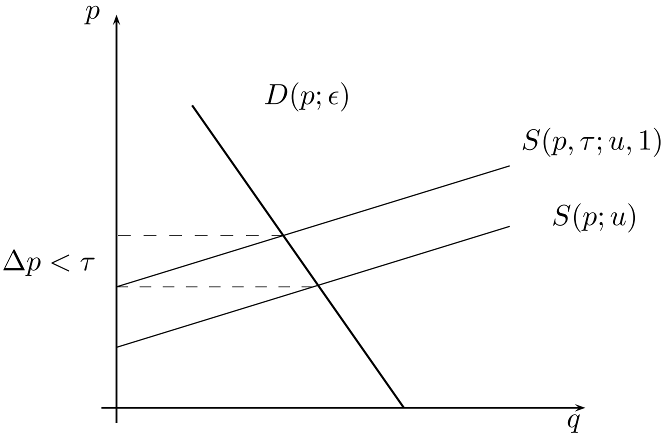
Goals:

- Separately identify internalization rate and pass-through.
- Decompose pass-through in supply-demand channels.

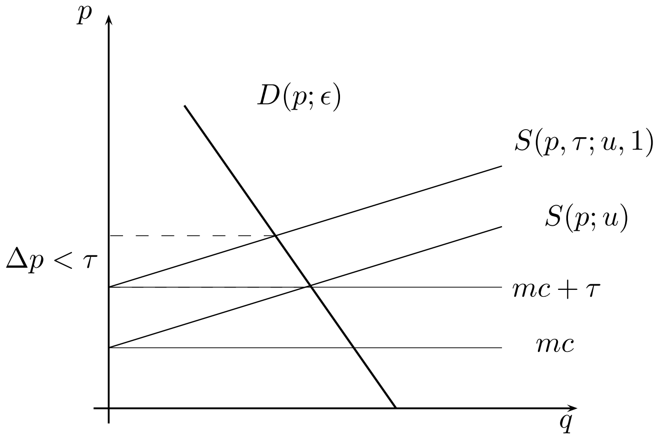
Internalization and pass-through

- Misconception that full internalization implies full pass-through if firms are competitive.
  - Only true under very particular assumptions.
- Internalization rate not always identified.
  - Need to assume full internalization to quantify pass-through.
- Take advantage of richness of electricity data to decompose the two.

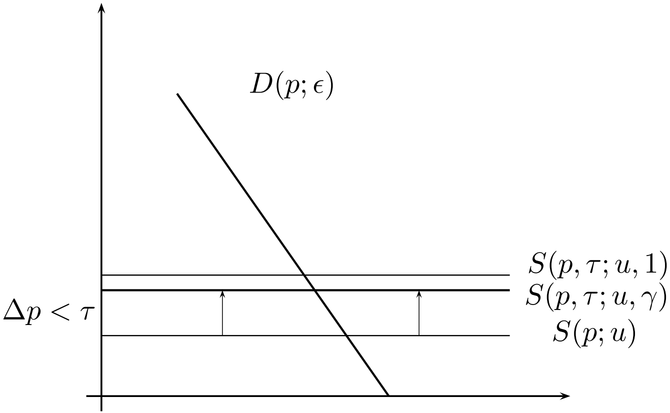
Incomplete pass-through and competitive behavior



Incomplete pass-through and market power



Incomplete pass-through and partial internalization



Preview of results

- Internalization rate is robustly estimated to be around one.
  - Across firms and also across different approaches/assumptions.
  - Identified at a high frequency (within-month variation).
- Price pass-through is around 50% and cost pass-through is close to 100%.
  - Price pass-through is a combination of heterogeneous cost shocks and substitution effects.
  - Cost pass-through is around 100%, but evidence of partial pass-through due to substitution. Demand effect is between 2-5% in the short-run.
  - Pass-through is sensitive to the frequency.

Related Literature

Internalization:

- Asymmetric internalization of emission costs (Kolstad and Wolak, 2008; Zachmann and Hirschhausen, 2007).
- Internalization for NO_x (Fowlie, 2010).
- Internalization for CO_2 (Ellerman and Reguant, 2008).

Pass-through:

- Empirical work on exchange pass-through (Goldberg, 1995).
- Other work on EU-ETS (Sijm et al, 2006).
- Marketing literature estimating pass-through (Besanko, 2008).

Data 2002-2007

Hourly data (Spanish electricity market):

- Supply curves and demand curves for all firms.
- Production for each of the units and market price.
- Unit that sets the market price.

Daily data:

- Price of inputs (natural gas, coal, fuel).
- Price of ETS CO_2 emission permits.

Empirical strategy overview

We perform a battery of tests for each concept.

	Internalization	Price PT	Cost PT
Auctions	around 1	avg. 0.50, het.	around 1, het.
On/Off	around 1		
Rank order	around 1		
Prices only		0.50-1.00	around 1, het.

Test based on optimal bidding

- Firm i's profits:

$$\pi_i\left(p; \epsilon, u\right) = \left(RD_i(p; \epsilon) - \theta_i\right) p - C\left(RD_i(p; \epsilon); u\right)$$

  where RD_i: residual demand; θ_i: forwards or retail sales.

- Profit maximization:

$$p = c'\left(q_i; u\right) + \gamma_i e_i \tau + \left|\frac{\partial RD_i}{\partial p}\right|^{-1} \left(q_i - \theta_i\right).$$

- We estimate this equation when firm i sets market price:

$$b_{iht} = \alpha_i + \beta X_{it} + \gamma_i e_i EUA_t + \left|\frac{\partial \overline{RD}^{bw}_{iht}}{\partial p_{ht}}\right|^{-1} \left(q_{iht} - \theta_{iht}\right) + \epsilon_{iht}.$$

Test based on optimal bidding: results

	Firm 1	Firm 2	Firm 3	Firm 4
(1) No FE-IV	1.077	1.026	1.149	1.094
	(0.051)	(0.057)	(0.056)	(0.080)
(2) Unit FE	0.989	0.866	0.988	1.057
	(0.026)	(0.035)	(0.046)	(0.082)
(3) Unit FE-IV	1.023	0.859	1.039	1.208
	(0.041)	(0.032)	(0.038)	(0.077)
(4) Unit FE + season-IV	1.014	0.859	0.975	1.237
	(0.037)	(0.028)	(0.043)	(0.085)
(5) Spec.4 + RD dummy	1.000	0.860	0.948	0.863
	(0.041)	(0.036)	(0.029)	(0.126)
(6) Spec.4 + RD excluded	1.001	1.028	0.701	0.977
	(0.031)	(0.035)	(0.086)	(0.112)
Obs.	5,368	3,274	5,693	2,093

Test based on participation decisions

- Firms decide whether to startup a plant or not a given day.
  - The decision depends on expected market prices and costs.
- Reduced-form decision rule:

$$on_{jt} = \begin{cases} 1 & \text{if } p_t \geq c'\left(q_{it}; u\right) + \gamma_i e_i \tau + u_{it} \\ 0 & \text{otherwise} \end{cases}$$

  where p_t: daily weighted price; u_{it}: unit fixed effects.
- We test whether $\beta_1 = -\gamma$ in:

$$on_{it} = \beta_1 p_t + \beta_2 X_{it} + \gamma e_i EUA_t + \alpha_i + \omega_t + \epsilon_{it}$$

Test based on participation decisions: results

	(1)	(2)	(3)	(4)	(5)	(6)
p_t $[\beta_1]$	8.813	10.601	5.420	5.437	4.669	4.379
	(0.610)	(0.906)	(0.916)	(0.914)	(0.824)	(0.815)
$e_i \tau_t$ $[\gamma]$	-6.588	-8.256	-5.431	-5.425	-5.027	-5.407
	(1.576)	(1.468)	(1.128)	(1.131)	(1.938)	(1.839)
γ / β_1	0.748	0.779	1.002	0.998	1.077	1.235
F-test	0.109	0.089	0.991	0.990	0.855	0.576
Obs.	87,213	87,213	39,206	39,206	39,206	39,206
Price IV	N	Y	Y	Y	Y	Y
Only OFF	N	N	Y	Y	Y	Y
Infra. Q	N	N	N	Y	Y	Y
yXm FE	N	N	N	N	Y	Y
wXu FE	N	N	N	N	N	Y

Test based on ranking among units

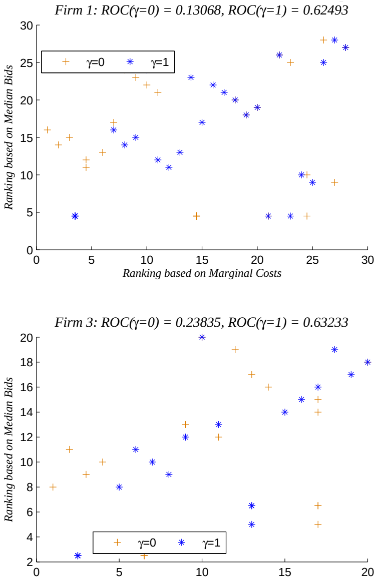
- Cost minimization:

$$\text{bids (low cost units)} < \text{bids (high cost units)}$$

- Changes in CO2 affect cost-based ranking among units and should also affect firms' supply functions if full internalization.
- What is the correlation between the ranking of units on the cost function and on each firm's supply function?
  - Spearman's correlation coefficient:

$$ROC = 1 - \frac{6 \sum_{i=1}^{n} (x_i - y_i)^2}{n(n^2 - 1)}.$$

Ranking on the cost curve vs. supply curve on a given hour



ROC results

	Firm 1	Firm 2	Firm 3	Firm 4
γ_{min}	*1.0900*	*1.0550*	*0.9150*	*1.0600*
γ_{max}	*1.1150*	*1.0550*	*0.9150*	*1.0650*
Maximum correlation	0.6279	0.8643	0.7006	0.6435
Correlation (γ=1)	0.6275	0.8636	0.6952	0.6427
Correlation (γ=0)	0.3919	0.7473	0.6125	0.3237

Notes: 1) ROC computed by using Spearman's rank correlation coefficient. 2) Sample from 01/01/2005 to 02/03/2006 (10224 observations) 3) We have tested if Means ($\gamma = 0$ and $\gamma = 1$) are equal. We always reject this null hypothesis.

Internalization rate: summary of findings

- Overall results are supportive of full internalization.
- All three models cannot reject full internalization.
- Estimates are economically close to one.
- Contributes to previous literature with conclusive evidence.

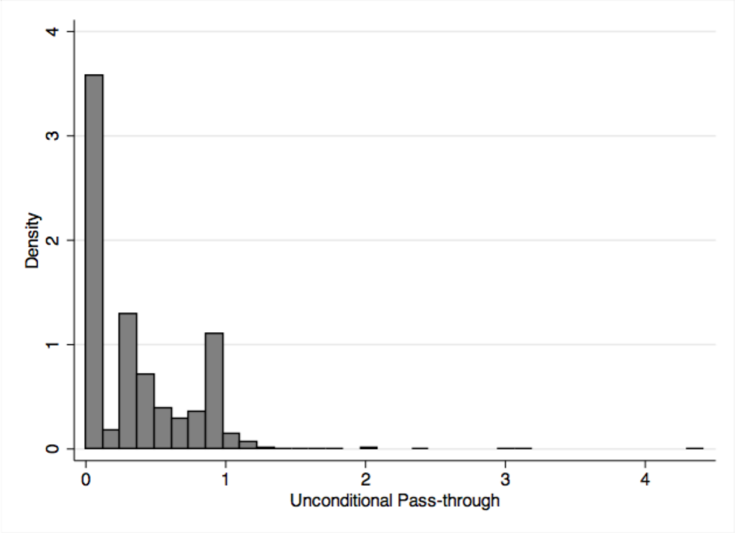
Quantification based on structural model

- Compute marginal pass-through from bidding equations by perturbing cost of CO_2 and re-computing optimal bids.
- Pass-through becomes:

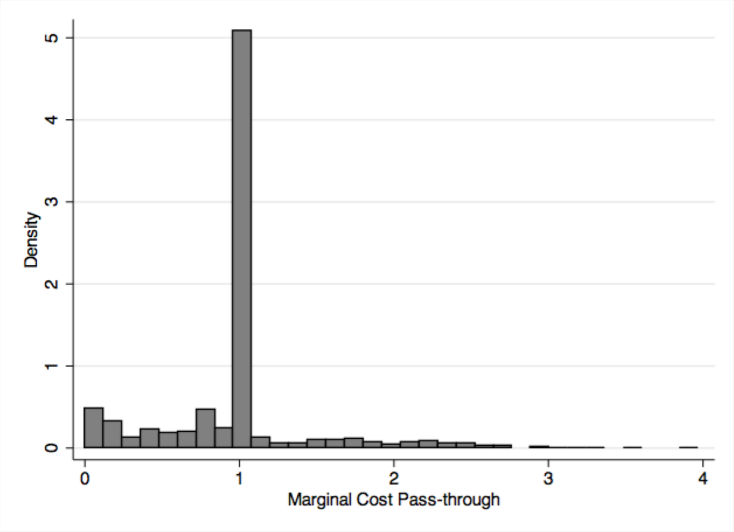
$$\frac{p^*(S(\tau + \epsilon), D) - p^*(S(\tau), D)}{\epsilon}$$

- Advantage: It appropriately accounts for endogenous changes of the marginal unit.
- Challenge: Limited to small changes, as bidding equations not sufficient to characterize startup patterns or other technologies (e.g. hydro).

Price pass-through



Cost pass-through



Quantification based on equilibrium outcomes

- Regress the electricity price on emissions price, controlling for exogenous variables that could affect the price and be correlated with CO_2 prices.
- Challenge: cost shock is heterogenous across firms.
  - Effective cost shock at the margin is endogenous if marginal technology changes due to carbon price.
- Baseline regression:

$$p_t = \rho EUA_t + Z_t^S \beta_1 + Z_t^D \beta_2 + \omega_t + \epsilon_t$$

where Z_t^S, Z_t^D: supply and demand exogenous shifters.

Quantification based on equilibrium outcomes: results

	(1)	(2)	(3)	(4)	(5)
$EUA_t(\rho)$ (valley)	1.172	1.177	1.033	0.572	0.434
	(0.009)	(0.029)	(0.060)	(0.058)	(0.100)
Obs.	30,648	30,648	21,888	30,648	21,888
"Basic" controls	N	Y	Y	Y	Y
RD Excluded	N	N	Y	N	Y
Month-year FE	N	N	N	Y	Y

Notes: Sample from January 2004 to June 2007, includes all thermal units in the Spanish electricity market. All regressions include hour, weekday, month, year and Royal Decree fixed effects. Standard errors clustered at the unit level.

Pass-through: summary of findings

- Price pass-through around 50% in equilibrium.
- Cost pass-through appears to be close to one in equilibrium.
- Heterogeneity goes in the expected direction.
- Further work needed to disentangle separate channels.

Conclusions and Future Work

- We explore the impact of emissions permits on firms' decisions and market outcomes.
- Good setting to think about identification strategies.
- Results consistent with full internalization of emission costs.
- Preliminary evidence of full pass-through.
- Future work required to quantify structural components of pass-through.

Thank You!