Fowlie et al. (2016)
"Market-Based Emissions Regulation and Industry Dynamics"

Hulai Zhang

Reading Group Env.Climate

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Outline

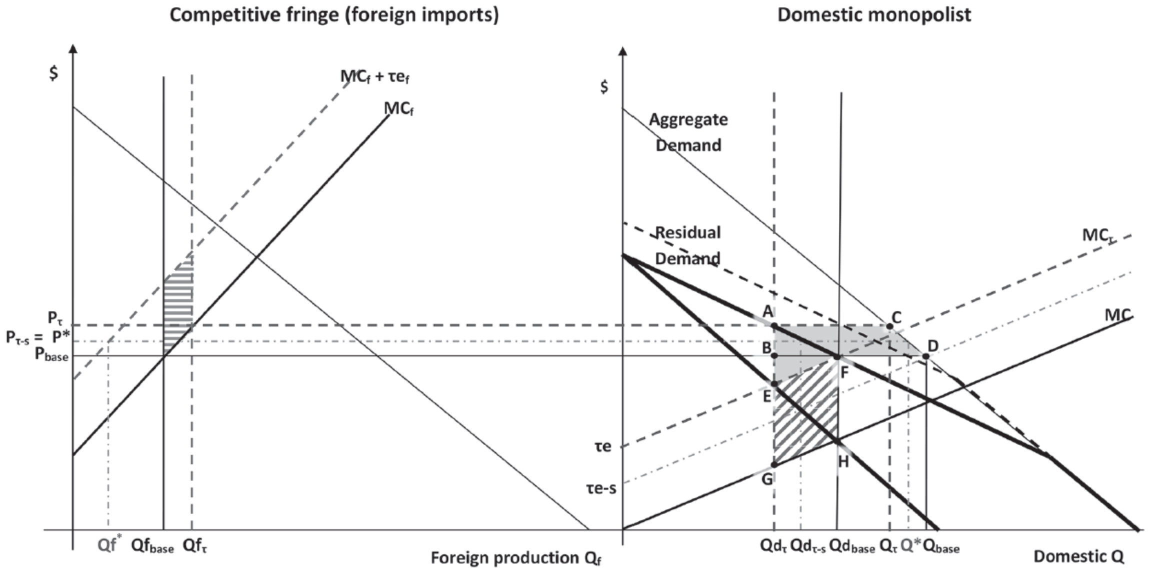
Introduction

What are industrial responses to environmental regulation?

- Four environmental regulation instruments
  - Auctioned permits
  - Grandfathering
  - Output-based allocation
  - Border tax adjustment
- Environmental regulation distorts market outcomes
  - Push productions more under the socially optimal level
  - Emission leakage to unregulated area

$\Rightarrow$ Compare the effects of the four environmental regulation instruments in a concentrated industry.

Conceptual Framework



The US Portland cement industry

- This industry plays large role in emissions to environment.
  - high energy requirements
  - emitting large amount of CO_2 in production
- This industry is highly concentrated.
  - 116 plants in 37 states, operated by 1 government and 40 firms in 2000
  - exporter competition is low but growing to 20%
- Cement are homogeneous good
  - Quantity competition

Data

Portland cement industry, 1980 – 2009

- Market-level data
  - US Geological Survey: the number of plants in each market, the quantity and prices of shipped cement
  - other market data such as prices of electricity, coal and natural gas, population and housing permits
- Plant-level data
  - Portland Cement Association's annual Plant Information Summary (PIS): capacity and production quantity by each plant, Kiln type

Model

- J markets: $j = 1, ..., J$
- $\bar{N}$ cement firms: $i = 1, ..., \bar{N}$
- Firm capacity $\{s_{it} : i \in \bar{N}\}$: $s_{1t}, s_{2t}, ...$
  - Firm with $s_{it} = 0$ is considered as potential entrant.
- Emission rate $\{e_i : i \in \bar{N}\}$: $e_1, e_2, ...$

Timeline

1. Firms receive private information
   - Incumbent firms receive private info on exit cost, decide whether exit or not; if not exit, they receive private info on investment/divestment costs
   - Potential entrants receive private info on entry cost
2. All firms decide on entry/exit and investment/divestment simultaneously
3. Incumbent firms compete over quantity
4. Firms enter/exit, and investments mature

Model

1. Demand: $\ln Q_{mt} = \alpha_m + \alpha_1 \ln P_{mt} + \alpha_2 X_{mt} + \epsilon_{mt}$
   - Instrument P_{mt} by coal prices, gas prices, electricity rates, and wage rates.
2. Import supply: $\ln M_{mt} = \rho_0 + \rho_1 \ln P_{mt} + \rho_{2m} + \rho_3' \ln Z_{mt} + \varepsilon_{mt}$
3. Firm's profit from production:
   $\bar{\pi}(s, e, \tau; \alpha, \rho, \delta) \equiv \max_{q_i \leq s_i} P\left(q_i + \sum_{j \neq i} q_j^*; \alpha, \rho\right) q_i - C_i\left(q_i; \delta\right) - \varphi\left(q_i, e_i, \tau\right)$
   - Production cost: $C_i(q) = \delta_1 q_i + \delta_2 1(q_i > \nu s_i)(q_i - \nu s_i)^2$
   - Environmental compliance cost: $\varphi(q_i, e_i, \tau)$
4. Investment adjustment cost:
   $\Gamma(x_i) = 1(x_i > 0)(\gamma_{i1} + \gamma_2 x_i + \gamma_3 x_i^2) + 1(x_i < 0)(\gamma_{i4} + \gamma_5 x_i + \gamma_6 x_i^2)$
   - Private info γ_{i1} and γ_{i4}: normal distribution $\mathcal{N}(\mu_\gamma^+, \sigma_\gamma^{+2})$ and $\mathcal{N}(\mu_\gamma^-, \sigma_\gamma^{-2})$
5. Entry/exit cost: $\Phi(a_i) = \begin{cases} -\kappa_i, & \text{if the firm is a new entrant} \\ \phi_i, & \text{if the firm exits} \end{cases}$
   - Private info κ_i and ϕ_i: normal distribution $\mathcal{N}(\mu_\kappa, \sigma_\kappa^2)$ and $\mathcal{N}(\mu_\phi, \sigma_\phi^2)$
6. Firm's period payoff: $\pi_{it}(a, x, s, e) = \bar{\pi}(s, e, \tau; \alpha, \rho, \delta) - \Gamma(x_{it}; \gamma) + \Phi(a_{it}; \kappa, \phi)$

Environmental compliance cost: $\varphi(q_i, e_i, \tau)$

Four market-bases environmental regulation instruments:

1. Auctioned permits: $\varphi(q_i, e_i, \tau) = \tau e_i q_i$
   - Social cost of carbon: $\tau \in [\$5, \$65]$
   - Emission rates: $e_i = 1.16, 0.93, 0.81$ for wet-, dry-, and state-of art kilns
2. Grandfathering: $\varphi(q_i, e_i, \tau) = \tau(e_i q_i - A_i) = \tau(e_i q_i - \psi_g e_i \min\{s_{i0}, s_i\})$
   - $\psi_g = 42.5\%$
3. Output-based allocation: $\varphi(q_i, e_i, \tau) = \tau(e_i - \psi_d) q_i$
   - $\psi_d = 0.716$
4. Border tax adjustment+Auction: $\varphi(q_i, e_i, \tau)$ and $\ln M_{mt} = \rho_0 + \rho_1 \ln(P_{mt} - \tau e_M) + \ldots$
   - e_M weighted emission rates over foreign cement producers

Model

Markov-perfect Nash Equilibrium (MPNE)

Given the setting above, there exists a pure strategy $\sigma_i : (s, e, \epsilon_i) \rightarrow a_i$ in equilibrium.

The proof is the same as Ryan (2012).

Estimation: Bajari, Benkard, and Levin (2007)'s two steps

Step 1: Generate Markov chains by agents

- $s_{it} \to (x_{it}, a_{it}) \to s_{it+1} \to (x_{it+1}, a_{it+1}) \to ...$
- $s_{it} \to (x_{it} + \epsilon_{\gamma}, a_{it} + \epsilon_{\kappa,\phi}) \to s^{'}_{it+1} \to (x_{it+1} + \epsilon_{\gamma}, a_{it+1} + \epsilon_{\kappa,\phi}) \to ...$
- ...

Step 2: Recover parameters

$$\min_{\theta} \frac{1}{n_k} \sum_{n=1}^{n_k} 1(V^* > \tilde{V})[V_i\left(s; \sigma_i^*(s), \sigma_{-i}(s), \theta, \varepsilon_i\right) - V_i\left(s; \tilde{\sigma}_i(s), \sigma_{-i}(s), \theta, \varepsilon_i\right)]^2 \tag{1}$$

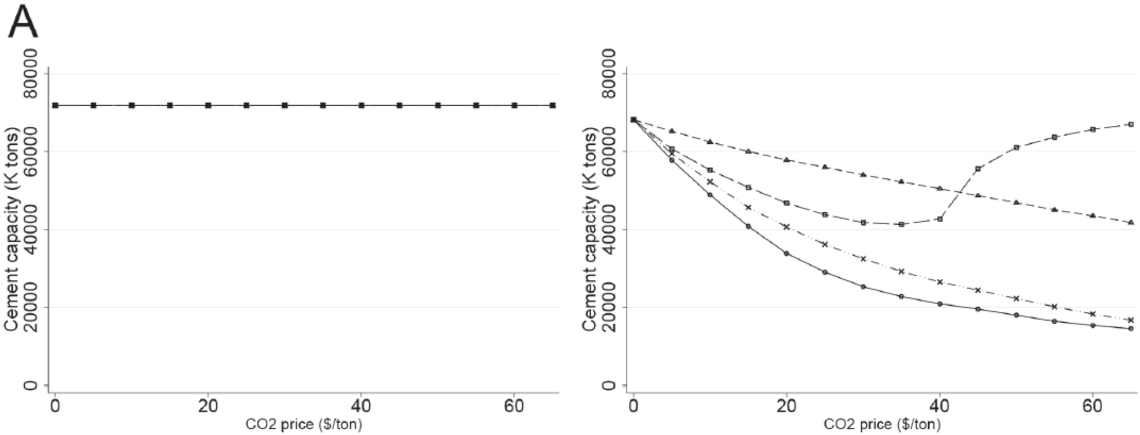
Estimation: Policy functions

$s_{it} \rightarrow s_{it+1}$: Adjust capacity if target s_{it} is located outside optimal band.

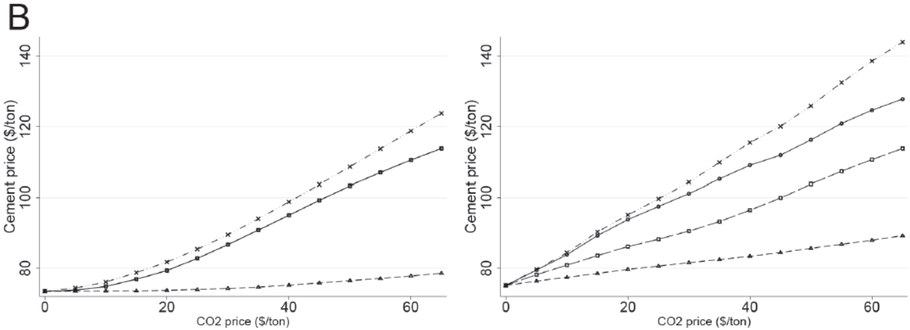
$$s_{t+1} = \begin{cases} T\left(s_t\right) & \text{if } s_t < T\left(s_t\right) - B\left(s_t\right) \text{ or } s_t > T\left(s_t\right) + B\left(s_t\right) \\ s_t & \text{else.} \end{cases} \tag{2}$$

- $\ln T_{imt}(s) = \eta_1 + \eta_2 1(i \text{ entrant }) + \eta_3[1 - 1(i \text{ entrant })] \text{ lnCapacity }_i + \eta_4 MT_m + \varepsilon_{\text{Timt}}$
- $\ln B_{imt}(s) = \eta_5 + \eta_6 \ln\text{Capacity }_i + \eta_7 MT_m + \varepsilon_{\text{Bimt}}$

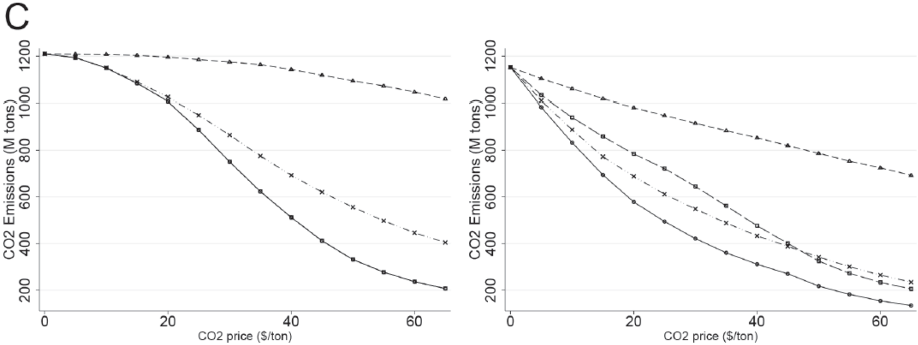
Capacity


A
Cement capacity (K tons)
0
20000
40000
60000
80000
CO2 price ($/ton)
0
20
40
60
Cement capacity (K tons)
0
20000
40000
60000
80000
CO2 price ($/ton)
0
20
40
60

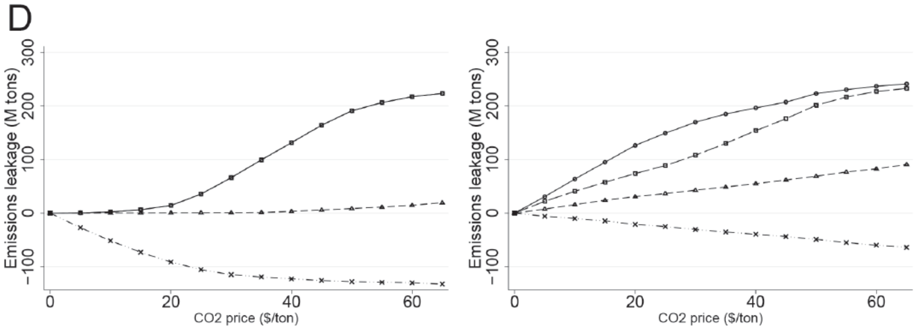
Price


B
Cement price ($/ton)
140
120
100
80
0
20
40
60
CO2 price ($/ton)
Cement price ($/ton)
140
120
100
80
0
20
40
60
CO2 price ($/ton)

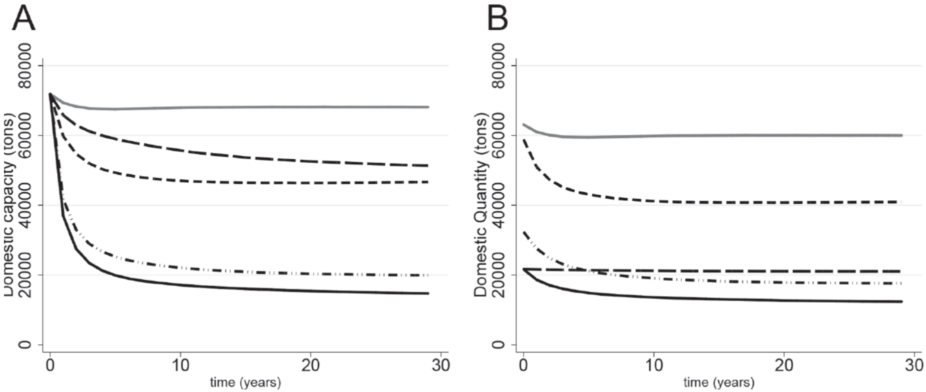
CO_2 emissions



Emission leakage



Market Dynamics



Welfare measures

Domestic economic surplus of cement consumption: consumer surplus, producer surplus, and government revenues:

$$w_1 = \int_0^{Q*} P(z;\alpha)dz - P(Q^*;\alpha)Q^* + \sum_i \Pi_i(a^*, x^*, s, e, \tau;\theta) + \sum_i \varphi(q_i^*, e_i, \tau) + \tau_M e_M M \quad (3)$$

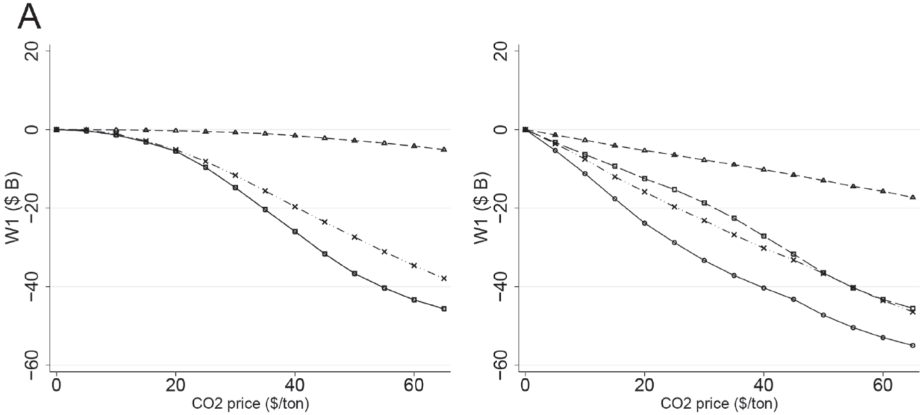
Adding domestic emission costs:

$$w_2 = w_1(s, e, \tau;\theta) - \tau \sum_i e_i q_i^* \quad (4)$$

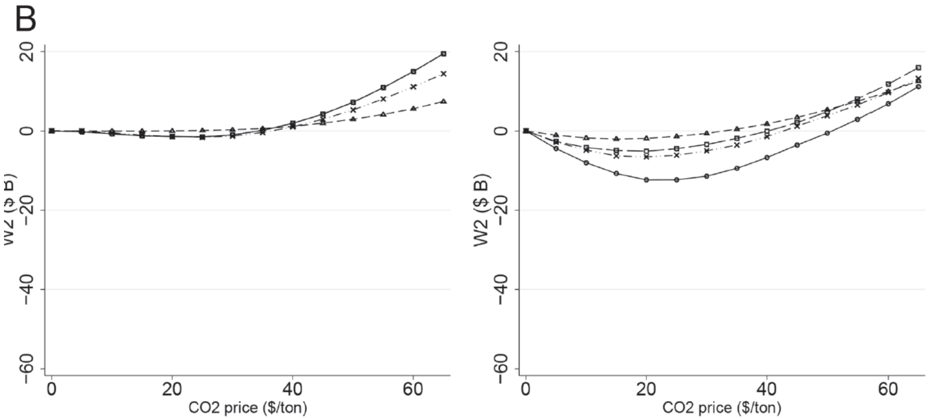
Adding penalty for emissions leakage:

$$w_3 = w_2(s, e, \tau;\theta) - \tau e_M M\left(P^*;\rho\right) \quad (5)$$

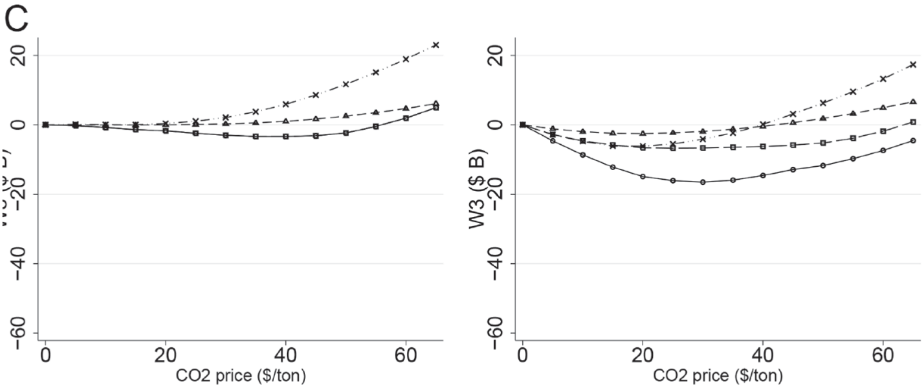
Welfare: Domestic economic surplus of cement consumption



Welfare: Adding domestic emission costs



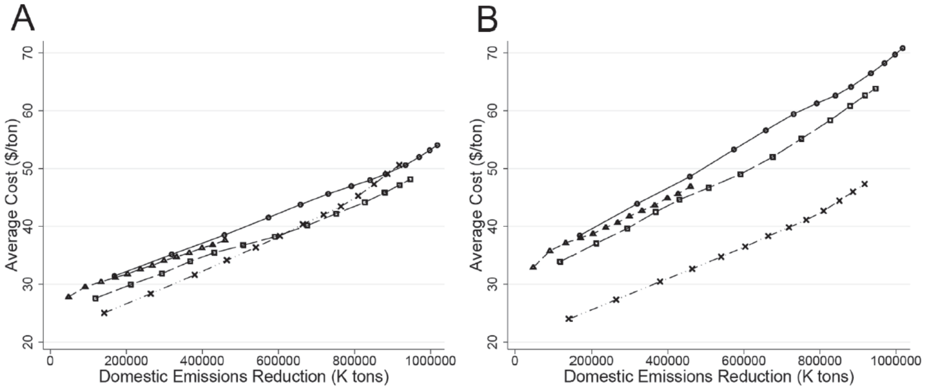
Welfare: Adding penalty for emissions leakage



Optimal carbon prices

	Federal τ_f^* (1)	Coastal τ_c^* (2)	Inland τ_i^* (3)	Welfare Δ at τ_f^* (4)	Welfare Δ at $\{\tau_c^*, \tau_i^*\}$ (5)	Welfare Δ at τ = SCC (6)
			A. SCC = \$20			
Auctioning	0	0	0	0	0	−14,886
Grandfather	0	0	0	0	0	−6,609
Output	0	0	0	0	0	−2,519
BTA	0	0	0	0	0	−6,141
			B. SCC = \$45			
Auctioning	5	5	15	905	1,316	−12,890
Grandfather	10	5	35	1,357	2,259	−5,839
Output	25	15	60	1,047	1,628	619
BTA	20	25	15	5,991	6,269	3,150

Abatement costs



Conclusion

- The effects of environmental regulation depend on how the policy is implemented and the social cost of carbon
  - At $40 SCC, auctioned permits exacerbates the distortions of market power
  - All four instruments push down market outcomes
- BTA and output-base allocations could increase welfare in high SCC.

References

Fowlie, M., M. Reguant, and S. P. Ryan (2016). Market-based emissions regulation and industry dynamics. *Journal of Political Economy 124*(1), 249–302.

Ryan, S. P. (2012). The costs of environmental regulation in a concentrated industry. *Econometrica 80*(3), 1019–1061.