HOW EFFECTIVE IS EMISSIONS PRICING? THE ROLE OF FIRM-PRODUCT-LEVEL ADJUSTMENT

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Motivation

- Climate change is one of the great challenges of our time.
- Human emissions of greenhouse gases (e.g. carbon emissions) are its most important drivers.
- They come primarily from production processes in energy-intensive industries (e.g. iron and steel, cement, paper, mineral, chemical, power plants, refineries,...).

Emissions pricing policies

Carbon markets:

- EU Emissions Trading System (2005):
  biggest carbon market in the world (covers around 45% of the region's greenhouse gas emissions)
- UN Clean Development Mechanism (2006)
- Chinese Certified Emissions Reductions (2013)

Margins of adjustment in production

Decomposition of changes in manufacturing emissions
(Grossman and Krueger 1993, Copeland and Taylor 1994):

1. total manufacturing output (scale)
2. product mix (composition)
3. emission intensity (technology)

Related literature

- Changes in emissions at the plant level:

  Cherniwchan et al. (2017), Barrows and Ollivier (2018), Shapiro and Walker (2018)

- Empirical impact of emissions regulations:

  Greenstone (2002, 2018), Ryan (2012), Martin et al. (2014), Abrell et al. 2022, Jonghe et al. (2020), Klementsen et al. (2020), Jaraite and Maria (2016), Wagner et al. (2020), and more

- Theory of multi-product firms:

  Eckel and Neary (2010), Dhingra (2013), Flach and Irlacher (2018)

A quantitative model of emissions in multi-product firms

In my model:

- Firms endogenously choose
  - how many products to produce (product scope),
  - how much to produce of each product (product scale),
  - how much to invest in emissions abatement of each product (technology).
- Production and emissions abatement choices depend on i) emissions pricing and ii) the cost structure of firms.

Demand

Utility:

$$U[\{u_s\}] = q_0 + \sum_{s=1}^{S} u_s,$$

$$u_s = a_s Q_s - \frac{1}{2} b_s \left((1 - \epsilon_s) \int_{i_s \in \Omega_s} q_s(i)^2 di + \epsilon_s Q_s^2 \right).$$

Budget constraint:

$$q_0 + \sum_{s=1}^{S} \int_{i_s \in \Omega_s} p_s(i_s) q_s(i_s) di_s = I.$$

Inverse market demand:

$$p_s(i_s) = a_s - b'_s \left[(1 - \epsilon_s) x_s(i_s) + \epsilon_s \int_{i_s \in \Omega_s} x_s(i_s) di_s \right], \; b'_s \equiv b_s / L, \; x_s(i_s) = L q_s(i_s).$$

Flexible manufacturing technology

Without emissions pricing:

$$c_s(i_s) = c_s + i_s^{\alpha_s} - 2k_s(i_s)^{0.5},$$

where $c_s > 0$ and $\alpha_s > 0$, $\forall\ s$.

With emissions pricing:

$$c'_s(i'_s) = d_s + i_s'^{\beta_s} - 2k'_s(i'_s)^{0.5} - 2\gamma_s l_s(i'_s)^{0.5},$$

where $d_s > 0$, $\gamma_s > 0$ and $\beta_s > 0$, $\forall\ s$.

Profit maximization

Without emissions pricing:

$$\Pi_s = \int_0^{M_s} \left[p_s(i_s) - c_s(i_s)\right] y_s(i_s) di_s - \int_0^{M_s} r_k k(i_s) di_s$$

With emissions pricing:

$$\Pi'_s = \int_0^{M'_s} \left[p'_s(i'_s) - c'_s(i'_s)\right] y'_s(i'_s) di'_s - \int_0^{M'_s} r_k k'(i'_s) di'_s - \int_0^{M'_s} r_l l(i'_s) di'_s,$$

where $y_s(i_s) = x_s(i_s) = Lq_s(i_s)$ and $y'_s(i'_s) = x'_s(i'_s) = Lq'_s(i'_s)$ due to market clearing, and r_k and r_l is the marginal cost of non-abatement technology and abatement technology, respectively.

Equilibrium without emissions pricing

Product scale:

$$x(i) = \frac{M^\alpha - i^\alpha}{2[b'(1-\epsilon) - \frac{1}{r_k}]}$$

Product-level investment:

$$k(i) = \frac{(M^\alpha - i^\alpha)^2}{[2(r_k b'(1-\epsilon) - 1)]^2}$$

Firm scale:

$$X = \frac{\alpha M^{1+\alpha}}{2(1+\alpha)[b'(1-\epsilon) - \frac{1}{r_k}]}$$

Product scope:

$$M = \left(a - c - b'\epsilon(1+N)X\right)^{\frac{1}{\alpha}}$$

Equilibrium with emissions pricing

Product scale:

$$x'(i') = \frac{M'^{\beta} - i'^{\beta}}{2[b'(1-\epsilon) - \frac{1}{r_k} - \frac{\gamma^2}{r_l}]}$$

Product-level investments:

$$k'(i') = \frac{(M'^{\beta} - i'^{\beta})^2}{4[b'(1-\epsilon)r_k - \gamma^2 r_k/r_l - 1]^2}$$

$$l(i') = \frac{\gamma^2(M'^{\beta} - i'^{\beta})^2}{4[b'(1-\epsilon)r_l - r_l/r_k - \gamma^2]^2}$$

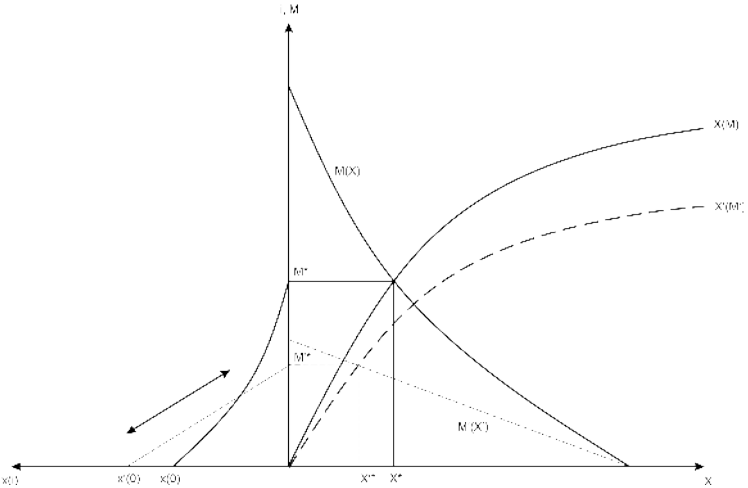
Firm scale:

$$X' = \frac{\beta M'^{1+\beta}}{2(1+\beta)[b'(1-\epsilon) - \frac{1}{r_k} - \frac{\gamma^2}{r_l}]}$$

Product scope:

$$M' = (a - d - b'\epsilon(1+N)X')^{\frac{1}{\beta}}$$

Firm-product-level effects of emissions pricing



Results I: Effects on firm-product scope, scale, and technology

Result 1. The effect of emissions pricing on product scope is negative (positive), if the scope elasticity of marginal cost increases (decreases). The effect on firm scale is ambiguous.

Result 2. The effect of emissions pricing on product scale is ambiguous.

Result 3. The effect of emissions pricing on product emission intensity is negative. The negative effect is stronger, the closer a product is to the core product.

Decomposition of emission changes

$$
\begin{aligned}
\hat{Z} \quad = \quad & \underbrace{\hat{Y}}_{\text{aggregate scale}} + \underbrace{\sum_{s=1}^{S} \frac{N_s Z_s}{Z} \widehat{\Theta}_s}_{\text{industry composition}} \\
& + \sum_{s=1}^{S} \frac{N_s Z_s}{Z} \underbrace{\int_0^{M_s} \frac{z_s(i)}{Z_s} \hat{\theta}_s(i)\, di}_{\text{product scale}} + \sum_{s=1}^{S} \frac{N_s Z_s}{Z} \underbrace{M_s \left(\frac{z_s(M_s)}{Z_s} - \theta_s(M_s) \right) \hat{M}_s}_{\text{product scope}} \\
& + \sum_{s=1}^{S} \frac{N_s Z_s}{Z} \underbrace{\int_0^{M_s} \frac{z_s(i)}{Z_s} \hat{e}_s(i)\, di,}_{\text{product emission intensity}}
\end{aligned}
$$

where $\Theta_s = Y_s/Y$ is the output share of industry s, $\theta_s(i) = N_s x_s(i)/Y_s = x_s(i)/X_s$ is the share of product i in output of (a representative firm in) industry s, and $e_s(i) = z_s(i)/x_s(i)$ is the emission intensity of product i in a firm in industry s.

Results II: Effects on emissions

Result 4. The effect of a change in product scope on emissions in response to an introduction of emissions pricing is zero.

Result 5. The effect of a change in product scale on emissions in response to an introduction of emissions pricing is ambiguous.

Result 6. The effect of a change in product emission intensity on emissions in response to an introduction of emissions pricing is negative.

Numerical results

Table: Effect of Emissions Pricing on Firm Emissions via Different Channels of Within-Firm Adjustment

	$\beta = 0.7$	$\beta = 1$	$\beta = 1.5$
Product scale	-0.06	-0.13	-0.28
(intensive+extensive)	(0.21-0.27)	(0.28-0.42)	(0.31-0.59)
Product scope	0	0	0
Product emission intensity	-0.37	-0.51	-0.66
(intensive+extensive)	(-0.11-0.25)	(-0.11-0.4)	(-0.10-0.56)

Note: Parameter values: $\alpha = 0.5$, $\gamma = 1$, $c = 10$, $d = 16$, $\epsilon = 0.7$, $b = 200$, $L = 1$, $a = 100$, $N = 10$, $r_k = r_l = 0.05$.

Conclusion

- The effectiveness of emissions regulation policies such as the EU Emission Trading Scheme highly depends on how firms adjust their production processes.
- Adjustment in multi-product firms does not unambiguously serve to reduce emissions:
  - Product scope decreases, if emission intensity decreases in product scale, and vice versa.
  - The relative scale of products with greater emission intensities may increase or decrease.
  - Abatement investment increases more for products with greater product scale.
- In numerical simulations, emissions decrease because firms drop their dirtiest products and, to a smaller extent, because of abatement investment in remaining products.
- Product mix changes within firms can be important for changes in aggregate emissions.
- Policies that target emission-intensive products directly may be more effective than general emissions pricing.