Multi-sector profit impacts of carbon pricing at the firm level

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1 Summary

Overview. This note presents a new model to estimate the profit impact of a carbon price at the firm (or product) level, in a way that is conducive to quick application across multiple firms and sectors. The model allows for product differentiation and emissions abatement among firms, and gives a new way to estimate cost pass-through rates at the firm- and market-level. It also suggests a simple way to deal with firm exit. The data requirements are different from RIMM/FIMM—but designed to be relatively low.

Empirical implementation.

Step 1: Perform cost pass-through analysis for period t, with the n^t original firms in the market. The (approximate) profit impact for firm i satisfies:

$$\frac{\Delta\Pi_i^t}{\Pi_i^{t-1}} \approx -(1-\rho_i^t)\frac{\Delta c_i^t}{c_i^{t-1}}\frac{(1-\mu_i^{t-1})}{\mu_i^{t-1}} - \eta^t\overline{\rho}^t\frac{\Delta\overline{c}^t}{\overline{c}^{t-1}}\frac{(1-\overline{\mu}^{t-1})}{\overline{\mu}^{t-1}}$$

where pass-through of firm i's cost change

$$\rho_i^t \equiv \frac{\Delta p_i^t}{\Delta c_i^t} = \frac{1}{[(1+\theta^t)-\gamma^t/\beta^t]}\left[(1-\gamma^t/\beta^t) + \frac{\theta^t(\gamma^t/\beta^t)n^t}{[(1+\theta^t)+(\gamma^t/\beta^t)(n^t-1)]}\left(\frac{\Delta\overline{c}^t}{\Delta c_i^t}\right)\right]$$

and the industry-average pass-through

$$\overline{\rho}^t \equiv \frac{\Delta\overline{p}^t}{\Delta\overline{c}^t} = \frac{1}{[(1+\theta^t)-\gamma^t/\beta^t]}\left[(1-\gamma^t/\beta^t) + \frac{\theta^t(\gamma^t/\beta^t)n^t}{[(1+\theta^t)+(\gamma^t/\beta^t)(n^t-1)]}\right]$$

Data requirements

- Firm i's cost change $\frac{\Delta c_i}{c_i}$ (including abatement opportunities)
- Average cost change $\frac{\Delta\overline{c}}{\overline{c}}$ (including abatement opportunities)
- Firm i's profit margin μ_i
- Average profit margin $\overline{\mu}$
- Price elasticity of market-level demand η
- Number of firms n
- Competitiveness parameter θ (default $\theta = 1$, Nash behaviour)
- Product differentiation γ/β (default $\gamma/\beta = 1$, no differentiation)

Step 2: Model the impacts of any exit decisions by firms

Check if any of the n^t original firms will exit the market (due to negative profitability). Firm i's profit margin becomes

$$m_i^t = m_i^{t-1} - (1-\rho_i^t)\Delta c_i^t$$

Case I. If $m_i^t \geq 0$ for all i, then no firm exits and the profit-impact analysis is complete.

Case II. If $m_k^t < 0$ for some firms $k \in n$, then do the following. Take the firm with the most negative profit margin (say $\widehat{k}$). This firm has the following output—which is now no longer supplied due to exit:

$$q_{\widehat{k}}^t = q_{\widehat{k}}^{t-1} + \Delta q_{\widehat{k}}^t = q_{\widehat{k}}^{t-1} + s_i^{t-1} \times \Delta Q^t$$

There are several potential ways to model the impact of this exit on other firms. Here assume that the surviving firms "fill the gap" arising from $q_{\widehat{k}}^t$ units dropping out in proportion to their market shares:

$$q_i^t = q_i^{t-1} + \Delta q_i^t = q_i^{t-1} + s_i^{t-1} \times \Delta Q^t \text{ (before } \widehat{k}\text{'s exit)}$$

$$\widetilde{q}_i^t = q_i^t + \frac{s_i^{t-1}}{(1 - s_{\widehat{k}}^{t-1})} \times q_{\widehat{k}}^t \text{ (impact of } \widehat{k}\text{'s exit)}$$

Note that prices are here unaffected by exit; only quantities respond. Real-world market responses probably contain both price and quantity adjustment—but determining this balance would require a more involved structural model.

Now repeat Case I vs Case II above with the remaining $n^t - 1$ firms.

2 Derivations

Profit decomposition. Suppose firm i's profits can be written as:

$$\Pi_i = (p_i - c_i)q_i = m_i s_i Q$$

where $m_i \equiv (p_i - c_i) > 0$ is its profit margin and $s_i \equiv q_i/Q \in (0, 1]$ is its market share. Note that this does not assume that there is a single market price; firms products can be differentiated or the law of one price may fail to hold for other reasons. The main assumption here is constant marginal costs. The analysis ignores fixed costs, and changes therein; the value of any freely allocated emissions permits is easily incorporated separately.

Carbon pricing raises firm i's own costs and may also raise the costs of some or all of its rivals. The change in its profits arising from carbon pricing τ therefore (approximately) satisfies:

$$\frac{\Delta \Pi_i}{\Pi_i} \approx \frac{\Delta m_i}{m_i} + \frac{\Delta s_i}{s_i} + \frac{\Delta Q}{Q}$$

Determining changes in market share Δs_i would require a structural model, so these are for now assumed to be negligible with $\Delta s_i \approx 0$, and so:

$$\frac{\Delta \Pi_i}{\Pi_i} \approx \frac{\Delta m_i}{m_i} + \frac{\Delta Q}{Q}$$

So the profit impact is driven by: (1) a firm-specific margin impact, and (2) a market-level sales impact.

Various definitions

- Price elasticity of market-level demand $\eta \equiv -\frac{\Delta Q}{\Delta \overline{p}} \frac{\overline{p}}{Q} > 0$ where $\overline{p}$ is the market-average price
- Firm i's change in unit cost Δc_i and the average unit cost change across firms $\Delta \overline{c}$

- Cost pass-through of firm i's cost change $\rho_i \equiv \frac{\Delta p_i}{\Delta c_i}$ and the average pass-through $\overline{\rho} \equiv \frac{\Delta \overline{p}}{\Delta \overline{c}}$
- Firm i's relative profit margin $\mu_i = \frac{(p_i - c_i)}{p_i}$ and the average profit margin $\overline{\mu} = \frac{(\overline{p} - \overline{c})}{\overline{p}}$

(1) Firm-specific margin impact

$$\begin{aligned} \Delta m_i &= (\Delta p_i - \Delta c_i) = -(1-\rho_i)\Delta c_i \\ &\implies \frac{\Delta m_i}{m_i} = -(1-\rho_i)\frac{\Delta c_i}{(p_i - c_i)} = -(1-\rho_i)\frac{\Delta c_i}{c_i}\frac{(1-\mu_i)}{\mu_i} \end{aligned}$$

So the firm-specific margin impact is more negative for a firm with low pass-through, a large cost shock, and low profitability.

(2) Market-level sales impact

$$\frac{\Delta Q}{Q} = -\eta\frac{\Delta\overline{p}}{\overline{p}} = -\eta\frac{\Delta\overline{p}}{\Delta\overline{c}}\frac{\Delta\overline{c}}{\overline{c}}\frac{\overline{c}}{\overline{p}} = -\eta\overline{\rho}\frac{\Delta\overline{c}}{\overline{c}}\frac{(1-\overline{\mu})}{\overline{\mu}}$$

So the market-level sales impact is more negative with a higher price elasticity of demand, and a greater average price increase.

Putting things together in the overall expression for the profit impact now gives:

$$\begin{aligned} \frac{\Delta\Pi_i}{\Pi_i} &\approx -(1-\rho_i)\frac{\Delta c_i}{c_i}\frac{(1-\mu_i)}{\mu_i} - \eta\frac{\Delta\overline{p}}{\overline{p}} \\ &= -(1-\rho_i)\frac{\Delta c_i}{c_i}\frac{(1-\mu_i)}{\mu_i} - \eta\overline{\rho}\frac{\Delta\overline{c}}{\overline{c}}\frac{(1-\overline{\mu})}{\overline{\mu}} \end{aligned}$$

This expression has the advantage of being *model-independent*. That is, it does not assume any particular mode of competition (e.g., Cournot, Bertrand, Hotelling, etc.); the expression holds for all such models (given the usual assumption of constant marginal costs).

Two further elements of the model can now be endogenized: the (1) magnitude of the cost change and (2) the pass-through rate(s)

(1) Magnitude of the cost change

- Let firm i's emissions e_i and its emissions intensity $z_i = e_i/q_i$
- Firm i's abatement effort
  - Firm i can reduce its emissions intensity by δ_i at cost $k_i(\delta_i)$, where $k_i(0) = k_i'(0) = 0$. The optimal abatement effort $\delta_i^* \equiv \arg\max_{\delta_i}\{\tau\delta_i - k_i(\delta_i)\}$ satisfies $\tau = k_i'(\delta_i^*)$, so the carbon price equals its marginal abatement cost (per unit of output)
    * I understand from Thomas that it is often possible to obtain firm-level $k_i(\alpha_i)$ from MAC curves
    * If abatement is unprofitable or otherwise infeasible, then $\delta_i \equiv 0$ and firm i's marginal cost increase is given by $\Delta c_i = \tau z_i$
  - Hence the gain in profits from abatement is $[\tau\delta_i^* - k_i(\delta_i^*)]$ per unit of output, and its optimal emissions intensity is $z_i - \delta_i^*$, and its marginal cost increase satisfies $\Delta c_i = [\tau(z_i - \delta_i^*) + k_i(\delta_i^*)] \leq \tau z_i$

(2) Pass-through rate(s)

- Suppose competition between n firms is in quantities and firm i faces inverse demand $p_i = \alpha_i - \beta q_i - \gamma Q_{-i}$ where $Q_{-i} \equiv \sum_{j \neq i} q_j$ and $\gamma/\beta \in [0,1]$ is an inverse measure of product differentiation ($\gamma/\beta = 1$ is no differentiation; $\gamma/\beta = 0$ is full differentiation).
  - The change in firm i's price therefore satisfies:

$$\Delta p_i = -\beta \Delta q_i - \gamma \Delta Q_{-i} = -(\beta - \gamma)\Delta q_i - \gamma \Delta Q$$

- Firm i solves $\max_{q_i}(p_i - c_i)q_i$ leading to the first-order condition $(p_i - c_i) = \beta\theta q_i$, where $\theta > 0$ is a parameter which measures the competitiveness of the market ($\theta = 1$ is Nash behaviour; lower θ are more competitive).

- Summing these n first-order conditions over all firms gives:

$$\textstyle\sum_i(\alpha_i - c_i) - \beta Q - \gamma(n-1)Q = n(\overline{\alpha} - \overline{c}) - \beta Q - \gamma(n-1)Q = \beta\theta Q$$

$$\Longrightarrow Q^* = \frac{n(\overline{\alpha} - \overline{c})}{[(1+\theta)\beta + \gamma(n-1)]} \Longrightarrow \Delta Q^* = -\frac{n\Delta\overline{c}}{[(1+\theta)\beta + \gamma(n-1)]} < 0$$

Note also that via the first-order condition:

$$(p_i - c_i) = (\alpha_i - \beta q_i - \gamma Q + \gamma q_i - c_i) = \beta\theta q_i$$

$$\Longrightarrow q_i^* = \frac{(\alpha_i - c_i) - \gamma Q}{[(1+\theta)\beta - \gamma]} \Longrightarrow \Delta q_i^* = -\frac{(\Delta c_i + \gamma\Delta Q^*)}{[(1+\theta)\beta - \gamma]}$$

Putting results together gives:

$$\begin{aligned}
\Delta p_i &= -(\beta-\gamma)\Delta q_i - \gamma\Delta Q \\
&= (\beta-\gamma)\frac{(\Delta c_i + \gamma\Delta Q^*)}{[(1+\theta)\beta - \gamma]} - \gamma\Delta Q \\
&= \frac{(\beta-\gamma)\Delta c_i}{[(1+\theta)\beta-\gamma]} - \gamma\left[1 - \frac{(\beta-\gamma)}{[(1+\theta)\beta-\gamma]}\right]\Delta Q \\
&= \frac{(\beta-\gamma)\Delta c_i}{[(1+\theta)\beta-\gamma]} - \frac{\theta\beta\gamma}{[(1+\theta)\beta-\gamma]}\Delta Q \\
&= \frac{(\beta-\gamma)\Delta c_i}{[(1+\theta)\beta-\gamma]} + \frac{\theta\beta\gamma}{[(1+\theta)\beta-\gamma]}\frac{n\Delta\overline{c}}{[(1+\theta)\beta+\gamma(n-1)]} \\
&= \frac{1}{[(1+\theta)\beta-\gamma]}\left[(\beta-\gamma)\Delta c_i + \frac{\theta\beta\gamma n}{[(1+\theta)\beta+\gamma(n-1)]}\Delta\overline{c}\right]
\end{aligned}$$

- So the increase in firm i's price from carbon pricing is:

$$\Delta p_i = \frac{1}{[(1+\theta) - (\gamma/\beta)]}\left[[1 - (\gamma/\beta)]\Delta c_i + \frac{\theta(\gamma/\beta)n}{[(1+\theta) + (\gamma/\beta)(n-1)]}\Delta\overline{c}\right]$$

and its pass-through rate is:

$$\begin{aligned}
\rho_i &\equiv \frac{\Delta p_i}{\Delta c_i} = \frac{1}{[(1+\theta) - \gamma/\beta]}\left[(1-\gamma/\beta) + \frac{\theta(\gamma/\beta)n}{[(1+\theta)+(\gamma/\beta)(n-1)]}\left(\frac{\Delta\overline{c}}{\Delta c_i}\right)\right] \\
&\equiv \rho_i(n, \theta, \gamma/\beta, \Delta c_i/\Delta\overline{c})
\end{aligned}$$

Pass-through is higher with more firms, less product differentiation, and more favourable cost exposure (relative to the industry average)

- Average price change is

$$\Delta\overline{p} = \frac{1}{n}\sum_i \Delta p_i = \frac{1}{n[(1+\theta)-\gamma/\beta]}\left[(1-\gamma/\beta)n\Delta\overline{c} + \frac{\theta(\gamma/\beta)n}{[(1+\theta)+(\gamma/\beta)(n-1)]}n\Delta\overline{c}\right]$$
$$= \frac{1}{[(1+\theta)-\gamma/\beta]}\left[(1-\gamma/\beta) + \frac{\theta(\gamma/\beta)n}{[(1+\theta)+(\gamma/\beta)(n-1)]}\right]\Delta\overline{c}$$

so average pass-through is:

$$\overline{\rho} \equiv \frac{\Delta\overline{p}}{\Delta\overline{c}} = \frac{1}{[(1+\theta)-\gamma/\beta]}\left[(1-\gamma/\beta) + \frac{\theta(\gamma/\beta)n}{[(1+\theta)+(\gamma/\beta)(n-1)]}\right]$$
$$\equiv \overline{\rho}(n,\theta,\gamma/\beta)$$

3 Additional material on electric utilities

Electric utilities are exposed to carbon pricing via at least two routes:

1. Direct impacts of carbon pricing as per the above
2. Indirect impacts via increased penetration of renewables

Consider utility i operating in market j. The overall share of electricity generation from RES in market j is $r_j \in [0,1]$ while a fraction of $1-r_j$ is from conventional generation. Suppose that the overall profits to conventional generation in market j are $\Pi_j(r_j) = (1-r_j)\overline{\Pi}$ where $\overline{\Pi}$ is the maximum profit. Utility i makes a share s_{ij} of this profit pool such that $\Pi_{ij}(s_{ij};r_j) = s_{ij}\Pi_j = s_{ij}(1-r_j)\overline{\Pi}$. Note that $\Pi_{ij}(s_{ij};1) = 0$.

Suppose that carbon pricing τ induces an increase in RES's share to r_j^*. Holding fixed its own share of non-RES generation s_{ij} and and the non-RES profit pool $\overline{\Pi}$, the change in utility i's profits is given by:

$$\frac{\Delta\Pi_{ij}}{\Pi_{ij}} = \frac{s_{ij}(1-r_j^*)\overline{\Pi} - s_{ij}(1-r_j)\overline{\Pi}}{s_{ij}(1-r_j)\overline{\Pi}} = -\frac{(r_j^*-r_j)}{(1-r_j)} < 0$$

These figures can then be aggregated across utility i's different markets. This would capture how the degree of RES penetration varies across markets—and hence across utilities.

Data requirement For each market j, figures for r_j and $\{s_{ij}\}_i$ should be easy to source for each market. I think we should be able to source r_j^* for different markets from scenarios developed by the IEA or national governments...

The analysis could be enriched by consider how the generation technology portfolio employed by utility i differs from its rivals. A nuclear-heavy utility, for example, may be able to raise its share of the profit pool (i.e., $s_{ij}(r_j^*) > s_{ij}(r_j)$) while a gas-heavy utility may lose disproportionately. These effects could be calculated if the future scenarios for r_j^* also include figure for the composition of the conventional generation.

Remark 1 *We need to be careful about the scope of this analysis. It is true that carbon pricing may incentivize renewables which erode incumbent utilitities' profits. However much existing renewables capacity has been driving by subsidies rather than carbon pricing;*

in other words, there are several different policies at work, not only carbon pricing. Similarly, carbon pricing could be in some way linked to the introduction of a capacity market or even other changes in corporate taxation—which will affect utilities' profits. We need to be clear about scope insofar as we are incorporating some of these additional policy channels but not all.