Profit impacts of carbon pricing at the firm level – application to electric utilities

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1 Summary

Overview. This note presents a new model to estimate the profit impact of a carbon price for electric utilities. The model allows for emissions abatement, and captures the direct impacts of carbon pricing as well as the indirect impacts via higher renewables penetration. The data requirements are different from RIMM/FIMM—but designed to be relatively low.

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 utilities' 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.*

Empirical implementation.

Step 1: Perform analysis for period t, with the n^t original utilities in the market. The (approximate) profit impact for utility i satisfies:

$$\frac{\Delta\Pi_i^t}{\Pi_i^{t-1}} \approx \frac{\Delta m_i^t}{m_i^{t-1}} + \frac{\Delta Q^t}{Q^{t-1}}$$

where the margin impact is

$$\frac{\Delta m_i^t}{m_i^{t-1}} = \left(\frac{n^t}{(n^t+\theta^t)}\frac{\Delta\overline{c}^t}{\Delta c_i^t} - 1\right)\frac{\Delta c_i^t}{c_i^{t-1}}\frac{(1-\mu_i)}{\mu_i^{t-1}} - \frac{1}{\eta^t}\frac{\theta^t}{(n^t+\theta^t)}\frac{1}{\mu_i^{t-1}}s_R^t g_R^t$$

and the sales impact is

$$\frac{\Delta Q^t}{Q^{t-1}} = -\frac{n^t}{(n^t+\theta^t)}\frac{\left[\eta^t\dfrac{\Delta\overline{c}^t}{\overline{c}^{t-1}}(1-\overline{\mu}^{t-1}) + s_R^t g_R^t\right]}{(1-s_R^t)}$$

Data requirements

- Utility 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)
- Utility i's profit margin μ_i
- Average profit margin $\overline{\mu}$
- Price elasticity of market-level demand η

- Number of utilities n
- Competitiveness parameter θ (default $\theta = 1$, Nash behaviour)
- Market share of renewables $s_R \equiv \frac{R}{(Q+R)}$ and its growth rate $g_R \equiv \Delta R/R$

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

$$m_i^t = m_i^{t-1} + \Delta m_i^t$$

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 the electricity industry has production of Q from conventional generation and R from renewable supplies (RES). Suppose utility i's profits can be written as:

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

where $m_i \equiv (p - c_i) > 0$ is its profit margin and $s_i \equiv q_i/Q \in (0, 1]$ is its market share (only) of the conventional output. 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 τ raises utility i's own costs and may also raise the costs of some or all of its rivals. It may also induce a change in the level of renewables production R.

The change in its profits (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 utility-specific margin impact, and (2) a market-level sales impact.

Various definitions

- Price elasticity of market-level demand $\eta \equiv -\frac{(\Delta Q+\Delta R)}{(Q+R)}\frac{p}{\Delta p} > 0$ where p is the market price
- Utility i's change in unit cost Δc_i and the average unit cost change across utilities $\Delta\overline{c}$
- Cost pass-through of firm i's cost change $\rho_i \equiv \frac{\Delta p}{\Delta c_i}$ and the average pass-through $\overline{\rho} \equiv \frac{\Delta p}{\Delta \overline{c}}$
- Utility i's relative profit margin $\mu_i = \frac{(p-c_i)}{p}$ and the average profit margin $\overline{\mu} = \frac{(p-\overline{c})}{\overline{p}}$
- Market share of renewables $s_R \equiv \frac{R}{(Q+R)} \geq 0$ and its growth rate $g_R \equiv \Delta R/R$

Magnitude of the cost change

- Let utility i's emissions e_i and its emissions intensity $z_i = e_i/q_i$
- Utility i's abatement effort
  - Utility 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)
    - If abatement is unprofitable or otherwise infeasible, then $\delta_i \equiv 0$ and 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 $\Delta c_i = [\tau(z_i - \delta_i^*) + k_i(\delta_i^*)] \leq \tau z_i$

Suppose competition between n utilities is in quantities with market demand curve $p = \alpha - \beta(Q + R)$, where $Q_{-i} \equiv \sum_{j\neq i} q_j$. Utility i solves $\max_{q_i}(p - c_i)q_i$ leading to the first-order condition $(p - c_i) = \beta\theta q_i$, where $\theta > 0$ is a parameter which measures the competitiveness of the market ($\theta = 1$ is Nash behaviour; lower θ are more competitive).

Because of the linear-demand structure, the two impacts of carbon pricing (via τ and R) are separable so write $\Delta p = \Delta p^\tau + \Delta p^R$, and similarly $\Delta Q = \Delta Q^\tau + \Delta Q^R$.

Summing the first-order condition over all n utilities gives:

$$n\left[\alpha - \beta(Q + R)\right] - n\overline{c} - \theta\beta Q = 0 \Rightarrow Q = \frac{n}{(n+\theta)}\left[\frac{(\alpha-\overline{c})}{\beta} - R\right]$$

where $\overline{c} \equiv \frac{1}{n}\sum_i c_i$. It follows that the two impacts are given by:

$$\Delta Q^\tau = -\frac{n}{\beta(n+\theta)}\Delta\overline{c} < 0 \text{ and } \Delta Q^R = -\frac{n}{(n+\theta)}\Delta R < 0$$

Conventional production declines both as a result of higher costs and of more RES competition. Since $p = \alpha - \beta(Q + R)$, the corresponding price impacts are:

$$\Delta p^\tau = -\beta\Delta Q^\tau = \frac{n}{(n+\theta)}\Delta\overline{c} > 0$$

and

$$\Delta p^R = -\beta(\Delta Q^R + \Delta R) = -\beta\left(-\frac{n}{(n+\theta)}\Delta R + \Delta R\right) = -\beta\frac{\theta}{(n+\theta)}\Delta R < 0$$

Note that the price impacts diverge; higher costs push price up but more RES supply pushes price down. This can also be written in terms of the price elasticity of demand:

$$\Delta p^R = -\frac{1}{\eta}p\frac{\theta}{(n+\theta)}\frac{\Delta R}{R}\frac{R}{(Q+R)} = -\frac{1}{\eta}p\frac{\theta}{(n+\theta)}rg_R$$

which uses

$$\eta = -\frac{p}{\Delta p}\frac{(\Delta Q + \Delta R)}{(Q+R)} \simeq \frac{p}{\beta}\frac{1}{(Q+R)} \Leftrightarrow \beta = \frac{p}{\eta}\frac{1}{(Q+R)}$$

(1) Utility-specific margin impact

The overall impact on utility i's profit margin is therefore given by:

$$\begin{aligned}
\frac{\Delta m_i}{m_i} &= \frac{(\Delta p - \Delta c_i)}{(p-c_i)} = \frac{(\Delta p^\tau + \Delta p^R - \Delta c_i)}{(p-c_i)} \\
&= \frac{\left(\frac{\Delta p^\tau}{\Delta c_i} - 1\right)\Delta c_i + \Delta p^R}{(p-c_i)} = \left(\frac{\Delta p^\tau}{\Delta c_i} - 1\right)\frac{\Delta c_i}{c_i}\frac{c_i}{(p-c_i)} + \frac{\Delta p^R}{(p-c_i)} \\
&= \left(\frac{n}{(n+\theta)}\frac{\Delta \bar{c}}{\Delta c_i} - 1\right)\frac{\Delta c_i}{c_i}\frac{c_i}{(p-c_i)} - \frac{1}{\eta}\frac{\theta}{(n+\theta)}\frac{\Delta R}{R}\frac{R}{(Q+R)}\frac{p}{(p-c_i)} \\
&= \left(\frac{n}{(n+\theta)}\frac{\Delta \bar{c}}{\Delta c_i} - 1\right)\frac{\Delta c_i}{c_i}\frac{(1-\mu_i)}{\mu_i} - \frac{1}{\eta}\frac{\theta}{(n+\theta)}\frac{1}{\mu_i}s_R g_R
\end{aligned}$$

where the last line uses the definitions of μ_i, s_R and g_R. The first term is certainly negative for a utility which experiences a larger-than average cost increase but turns positive if $\Delta c_i/\Delta\bar{c} < n/(n+\theta)$. The second term is unambiguously negative; more RES supply squeezes margins via a merit-order effect.

(2) Market-level sales impact

The overall impact on market-level sales is therefore given by:

$$\begin{aligned}
\frac{\Delta Q}{Q} &= -\eta\frac{\Delta p}{p}\frac{(Q+R)}{Q} - \frac{\Delta R}{Q} = -\eta\frac{(\Delta p^\tau + \Delta p^R)}{p}\frac{(Q+R)}{Q} - \frac{\Delta R}{Q} \\
&= -\eta\frac{\left(\frac{n}{(n+\theta)}\Delta\bar{c} - p\frac{1}{\eta}\frac{\theta}{(n+\theta)}\frac{\Delta R}{R}\frac{R}{(Q+R)}\right)}{p}\frac{(Q+R)}{Q} - \frac{\Delta R}{Q} \\
&= -\eta\frac{n}{(n+\theta)}\frac{\Delta\bar{c}}{\bar{c}}\frac{\bar{c}}{p}\frac{(Q+R)}{Q} + \frac{\theta}{(n+\theta)}\frac{\Delta R}{R}\frac{R}{(Q+R)}\frac{(Q+R)}{Q} - \frac{\Delta R}{Q} \\
&= -\eta\frac{n}{(n+\theta)}\frac{\Delta\bar{c}}{\bar{c}}\frac{\bar{c}}{p}\frac{(Q+R)}{Q} + \frac{\theta}{(n+\theta)}\frac{\Delta R}{Q} - \frac{\Delta R}{Q} \\
&= -\eta\frac{n}{(n+\theta)}\frac{\Delta\bar{c}}{\bar{c}}\frac{\bar{c}}{p}\frac{(Q+R)}{Q} - \frac{n}{(n+\theta)}\frac{\Delta R}{Q} \\
&= -\eta\frac{n}{(n+\theta)}\frac{\Delta\bar{c}}{\bar{c}}\frac{\bar{c}}{p}\frac{(Q+R)}{Q} - \frac{n}{(n+\theta)}\frac{\Delta R}{R}\frac{R}{(Q+R)}\frac{(Q+R)}{Q} \\
&= -\frac{n}{(n+\theta)}\frac{\left[\eta\frac{\Delta\bar{c}}{\bar{c}}(1-\bar{\mu}) + s_R g_R\right]}{(1-s_R)}
\end{aligned}$$

This cutback is more pronounced, e.g., if the industry is more competitive, the cost increases from carbon pricing are greater, the demand elasticity is greater or if renewables' share/growth is greater.

3 Backup: alternative (simpler) method

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...