Carbon Abatement as a Strategic Variable: Implication for Energy Suppliers in a Carbon-Constrained Environment

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Overview

Market-based incentives are becoming increasingly popular relative to centralised directives in policy prescriptions for the purpose of environmental regulations. These approaches aim to create an incentive for the private sector to incorporate pollution abatement processes into achieving least cost methods of production. This paper presents one such framework. We argue that regulatory instruments can be used to provide economic incentive for the use of environmentally friendly technologies when augmented by appropriate market structures and demonstrate this case with reference to the duopoly model; the results of which are then extended to the *n*-player oligopoly. The most significant part of the results of this analysis is the demonstration of the prisoner's dilemma equilibrium in the use of cost-reducing technology. This equilibrium is of great significance since it counteracts the argument that the presence of market power, a form of market failure, renders policy measures ineffective and cause additional inefficiencies.

This analysis fits broadly into the discipline of Industrial Organisation, which contributes to our understanding of the determinants of strategic interactions, market design and market structure driving transition to lower carbon economies (Fabra 2021).

This analysis differs from those that focus on comparing the relative merits of carbon tax, tradable permits and command and control mechanisms. It also differs from literature dealing with strategic behaviour of firms to gain market power by manipulating the price of tradable permits for instance (Misiolek and Elder 1989, Salop and Scheffman 1987 and Krattenmmaker and Salop 1986), and thereby affect industry dynamics. (Hahn 1984; Hahn and Noll 1982, Maloney and Yandle 1984; and Pototschnig 1994).

Environmental policy

Good (A) is currently produced using a combination of inputs and processes (OT for old technology) with negative externalities that have an adverse impact on the environment. Assume also that an alternative set of inputs and processes (NT for new technology) that have a less negative impact on the environment and are also available to the firm. NT costs more to adopt. An example of OT would be coal-generated electricity while NT could represent an energy mix of gas, solar, hydrogen, wind, ocean-generated electricity which in combination can be used to produce good A.

In an unregulated environment, the negative externality associated with the production of good A goes unmeasured and hence the marginal cost of producing a unit of good A is simply the cost of producing a unit of that output.

$$C_A = C_{Output} = C_{mc}$$

Environmental regulations effectively measure the negative externality associated with the production of good A. The method of environmental regulation, be it through Pigouvian tax, tradable permits or command and control mechanism, essentially are a method of costing out negative externalities associated with production. The cost of producing a unit of good A in a regulated environment is:

$$C_A = C_{output} + C_E = C_{mc}$$

Assuming, all consumers have complete and perfect knowledge of the shift in policy, consumers see the good A, as differentiated good. Good A is now differentiated as Good A and Good A′. A′ may be defined as the "good" good and that means that more of the good is preferred to less of this good and A the "bad good", such that less of this good is preferred to more of this good.

The tighter the policy, through pricing of the externality, the greater the proportion of total cost that the externality measures.

$$C_E/C_A > C_O/C_A$$

C_E=αC_A such that α is a measure of the tightness or looseness of environmental policies. Once the environmental policy has been implemented, firms in the regulated environment face a higher cost structure. The firm may pass on the higher production cost to the consumers; or aim to reduce production cost via either implementing processes that reduce the cost of producing each unit of output, while bearing the cost of the externality. Under this choice, however the firm may face reduced demand due to its reputation for producing the "bad good". Given the premise that a profit-maximising firm, and that good A′ is the preferred good, then a reasonable outcome is that the firm has an incentive to use technology Y to minimise its costs. Theoretically, the firm has three different options of doing this, either through the reduction of its sheer output cost, or attempting to decrease the cost of the externality or through both.

Hence the analysis is restricted by the assumption that the firm is only able to reduce its overall cost by reducing its externality cost.

$$C_A^{NT} = C_O^{OT} + C_E^{NT}$$

Market structures in the context of environmental regulations

Monopoly

Firms facing higher costs due to the costing out of the externality, attempt to minimize costs and maximise residual claims by internalizing the benefit of their investment in cost reduction. One such means of cost minimisation is to invest in cost reduction efforts depicted by *e*.

$$\pi(q) = pq - c(q) \tag{1a}$$

$$\pi(q, e) = pq - c(q, e) \tag{1b}$$

A firm in the newly regulated environment profit maximises according to the equation 1b; where the costs of production $c(q, e)$ depend not only level of the firm (*q)* but also its investment in cost reduction or its efforts to minimise costs. Increases in *e* reduce the cost of the firm. The rate at which increases in efforts, e, reduce costs is given by ${}^{dc}/_{de}$< 0.

The profit maximising output for a price-taking firm (as always) equates price equal marginal cost. The firm will invest in *cost reduction until the marginal benefits of cost reduction equal the marginal cost*:

The firm will invest in cost reduction only until the marginal benefit of cost reduction equals the marginal cost (Church and Ware 2000, p 67):

$$-\frac{dc\,(q,^{*}e^{*})}{de} = 1, \text{ where } q^{*}\ and\ e^{*} \text{ are the profit -maximising quantity and effort level.}$$

Monopolies and large firms that dominate the market concern themselves with the most efficient means of cost reduction, without paying any attention to the issue of gaining market share via strategic behaviour.

Duopoly

Suppose that the firm X is a duopoly with its competitor firm Y facing an identical demand curve. They share the market, face a common demand schedule, and own a constant cost specification with constant returns to scale. The model is based on Martin (1993, pp.11-21), which assumes a market demand with the parameters:

The demand curve may be expressed as:

$$\begin{aligned} P &= a - bQ \\ &= a - b(q_X + q_Y) \\ &= a - bq_X - bq_Y \end{aligned}$$

The cost structure assumes constant returns to technology and is written as

$$C(q_i) = cq_i$$

The non-strategic partial equilibrium solution for firm X is given by the equation

$a - 2bq_X - bq_Y = c$, such that $q_X = \frac{1}{2}[S - q_Y]$ and$q_Y = \frac{1}{2}[S - q_X]$, and S a measure of market size, in terms of output (Martin 1993, p.15) equals $\left[\frac{a-c}{b}\right]$for both firms given the symmetry assumption.

The Cournot non-co-operative equilibrium output pair for the pair of firms is $q_X = q_Y$ and the non-co-operative price for this level of equilibrium output is $P = c + \frac{1}{3}bS$ (Martin 1993, p.19).

Rival firms can behave strategically to take away their rival's market share. In this analysis only cost-reduction strategies are considered. Suppose we alter the specification of the previous model to allow for cost differentials between the two rival firms. In the most general terms, the equation can be stated as:

$$C(q_i) = c_i q_i \qquad\qquad i=X,Y$$

Without loss of generality, let $c_X < c_Y$, then $q_X = \frac{1}{2(S_X - q_Y)}$ and $q_Y = (S_Y - q_X)$; then

$$S_X = \frac{(a - c_X)}{b} > \frac{(a - c_Y)}{b} = S_Y$$

The firm with the lower cost structure has a higher market share.

Strategic behaviour with the aim of gaining market share through cost reduction is analysed. There exists environmentally friendly technology (NT) which reduce cq_E with a fixed cost of R. Each of the firms X and Y have the choice of either using the technology or not using that technology. The firm that uses the environmentally friendly technology (NT) incurs the cost of R but reduces its externality exactly to zero. As a result, cost structure for the firm which implements the new technology is a fraction of the rival's cost structure so that $fc < c$, where f is a value between $0 < f < 1$. The difference in the cost structure between the two firms in the industry translates to market power to the firm with the lower cost, according to the Lerner index, $\left[\frac{P-c_i}{P}\right]$(Martin 1993, p.27). The firm that uses the environmentally friendly technology reduces all its externality cost and achieves a lower cost structure relative to the firm that does not.

A two-player and two-strategy game theoretical analysis in its normal form is then developed. The two players are the two firms X and Y and the two strategies (namely *not* use the new technology NT; or to use the new Technology NT are depicted as strategy 1 and 2 respectively). The first of these scenarios occurs where neither of the firms implements the new technology. In such a situation, given the assumptions of the model, both the firms have an identical cost structure such that $c_X = c_Y = Cq_i = cq_i + cq_E$. The second and third situation is when the firm X uses the NT and has a lower cost structure than its rival Firm Y and vice versa. The final scenario is the case when both firms use the NT. The payoffs to each of these strategies for each of the players are derived from the basic Cournot parameters :

In summary, the payoffs to the players under the four different scenarios are as follows:

$x_{11} = y_{11} = \frac{(a-c)^2}{9b}$; $x_{21} = \frac{(a+c-2fc)^2}{9b}$; $y_{21} = \frac{(a-2c+fc)^2}{9b}$; $x_{12} = \frac{(a-2c+fc)^2}{9b}$;

$y_{12} = \frac{(a+c-2fc)^2}{9b}$ and $x_{22} = y_{22} = \frac{(a-fc)^2}{9b}$.

The cost of investing in NT is derived as in terms of these payoffs. When the cost of investing in the new technology R, is zero, the ordering of the payoffs is as follows: $x_{21} > x_{22} > x_{11} > x_{12}$ and $y_{21} > y_{22} > y_{11} > y_{12}$.

As the cost of the technology increases (that is, the differences between the cost structures when one of the firms uses the technology and when it does not) the returns to the investment changes. The value of R is dependent upon the tightness and or looseness of the environmental policy.

CRITICAL (R) VALUE	**PAYOFF ORDERING**		
	MATRIX A		
$R = 0$	$x_{12} < x_{11} < x_{22} < x_{21}$	x_{11} 1	x_{12} 4
		x_{21} 2	x_{22} 3
	MATRIX B		
$R > \frac{(2a-c-fc)(c-fc)}{9b}$	$x_{12} < x_{22} < x_{11} < x_{21}$	x_{11} 1	x_{12} 4
		x_{21} 2	x_{22} 3
	MATRIX C		
$R > \frac{4(a-c)(c-fc)}{9b}$	$x_{22} < x_{12} < x_{11} < x_{21}$	x_{11} 1	x_{12} 4
		x_{21} 2	x_{22} 3
	MATRIX D		
$R > \frac{4(a-fc)(c-fc)}{9b}$	$x_{22} < x_{12} < x_{21} < x_{11}$	x_{11} 1	x_{12} 4
		x_{21}	x_{22} 3
	MATRIX E		
$R > \frac{3(2a-c-fc)(c-fc)}{9b}$	$x_{22} < x_{21} < x_{12} < x_{11}$	x_{11} 1	x_{12} 4
		x_{21} 2	x_{22} 3

Interpretation
When the value of R (the cost of using the environmentally friendly technology) is low as in the two cells matrix A and B, a dominant equilibrium strategy exists such that both players use the environmentally friendly technology. As a result, the externality is completely internalised. The total market demand is supplied using the technologies that internalises the externality. Socially optimal quantities are produced with the environmentally friendly technology.

When the value of R is prohibitively high as in the two cells matrix D and E, the dominant strategy is that neither of the two players use the environmentally friendly technology. This means that the entire industry is supplied without using the new environmentally friendly technology. None of the externality is internalised. In the extreme case, depending on public policy, these industries may no longer exist, if the demand for goods are elastic with respect their preferences for goods that are “clean”.

At the intermediate cost of the technology various strategies with corresponding equilibria are possible. The most significant of these is the non-cooperative Nash equilibrium with Prisoner’s dilemma outcome. At the intermediate cost of the technology, the environmentally friendly technology becomes a potent strategic variable. At this cost, each firm takes into consideration the likely choice of its’ competitor in their use of the environmentally friendly technology. When one of the players uses the environmentally friendly technology, while the other does not, the firm that does not use that technology is said to lose their market share to its competitor. As a response, the other firm also will use the technology to gain the market share. However, if both firms use the technology at the same time, when the cost structure is such that their margins are eroded, both players are made worse off while following their dominant strategy. Consumers benefit while producers are made worse off. These results carry over to the n>2, case of an oligopoly.

Oligopoly
The effect of a cost-reducing technology for an N-player symmetrical oligopoly in the identically regulated environment is analysed. As with the duopoly situation, before, two linear cost strategies with two technologies, C_1 (OT) and C_2(NT) exist. In general terms, $C_i(q) = a_i q + b_i$. The new technology has greater marginal efficiency so that $a_2 < a_1$; but has greater fixed costs, $b_2 > b_1$. The general twice differentiable demand curve with $D'(q) < 0$, $D''(q) \geq 0$ and therefore $\frac{d^2}{dq^2} qD(q) < 0$.

The Cournot (Nash) competition for quantities may be written as: $q_i = (argmax) q_i \pi_i(q_i; q_i\{j \neq i\})$. On the assumption that *n* out of the total N players take up the strategy of using the NT technology, the individual profit for each player using the NT and incurring a fixed cost of b_i is given by the function $\pi_i(n) = \ q_i(n)D\big(q(n)\big) - a_i q_i(n) - b_i$.

As in the duopoly analysis, in the generalised oligopoly profit function is affected by the fixed cost of the NT. Changes in the fixed cost of NT, effectively translates the profit function as shown pictorially. Three to four phases corresponding to the matrices A-E result with reference to the analysis. When the fixed cost is high neither producers nor consumers benefit as no firm in the industry will uptake the environmentally friendly technology (NT). At medium cost of the technology consumers benefit (akin the prisoner’s dilemma outcome) while at low cost or zero cost, producers benefit.

Conclusion
These insights follow:

1) Environmental policies are a means to measure or cost out externalities, at least theoretically. The tightness or looseness of the environmental policies, make a difference through the cost structure and relative cost differentials. Tight policies make it relatively costly for firms NOT using abatement technologies.
2) Industry Structure matters: The decision to take up abatement technology or not take up the technology is based upon the industry structure. Industries with duopoly and oligopoly structures can have outcomes that benefit and encourage consumers and bring out optimal social welfare, particularly when prisoner’s dilemma results.
3) Optimal industry structure: optimal climate policies are industry specifics. No generalisations but industry specific solutions. Dependent upon the parameters and cost structure of the industry.

Our analysis allows the following conclusions. Firstly, environment policies provide economic incentives for the use of abatement technologies. The deployment of these is not costless, and tightness or looseness of environmental policies influences the relative costs of the decision to deploy at the margins. Secondly, market structures of energy suppliers, affect decisions to deploy or otherwise. The possibility of gaining market power in oligopolies, provide the impetus to use abatement technologies. Deploying abatement technologies can bring about changes in industry structure. Our framework lends itself to empirical application for determining optimal market structure of each industry.

References

André, F. J., & Arguedas, C. (2018). Technology Adoption in Emission Trading Programs with Market Power. *The Energy Journal*, *39*(01). https://doi.org/10.5547/01956574.39.SI1.fand

Bloch, H., & Voola, J. (2004). Strategic Responses to Advances in Seismic Technology in the Petroleum Industry. *International Journal of the Economics of Business*, *11*(1), 27–36. https://doi.org/10.1080/1357151032000172219

Church, J. R., & Ware, R. (2000). *Industrial organization: a strategic approach*. Irwin McGraw Hill.

Fabra, N. (2021). The energy transition: An industrial economics perspective. *International Journal of Industrial Organization*, 102734. https://doi.org/10.1016/j.ijindorg.2021.102734

Färe, R., Grosskopf, S., Noh, D.-W., & Weber, W. (2005). Characteristics of a polluting technology: theory and practice. *Journal of Econometrics*, *126*(2), 469–492. https://doi.org/10.1016/j.jeconom.2004.05.010

Hahn, R. W. (1984). Market Power and Transferable Property Rights. *The Quarterly Journal of Economics*, *99*(4), 753–765. https://doi.org/10.2307/1883124

Hahn, R. W., & Noll, R. G. (1982). Designing a market for tradable emissions permits. In W. A. Magat (Ed.), *Reform of Environmental Regulation* (pp. 119–146). Ballinger Publishing Co. https://resolver.caltech.edu/CaltechAUTHORS:20171116-154446842

Jung, C., Krutilla, K., & Boyd, R. (1996). Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives. *Journal of Environmental Economics and Management*, *30*(1), 95–111. https://econpapers.repec.org/article/eeejeeman/v_3a30_3ay_3a1996_3ai_3a1_3ap_3a95-111.htm

Krattenmaker, T. G., & Salop, S. C. (1986). Competition and Cooperation in the Market for Exclusionary Rights. *The American Economic Review*, *76*(2), 109–113. https://www.jstor.org/stable/1818746

Maloney, M. T., & Yandle, B. (1984). Estimation of the cost of air pollution control regulation. *Journal of Environmental Economics and Management*, *11*(3), 244–263. https://doi.org/10.1016/0095-0696(84)90020-2

Matysek, A., Ford, M., Jakeman, G., Gurney, A. & Fisher, B. S (2006). Technology, its role in economic development and Climate Change. ABARE Research Report 06.6, July 2006

Milliman, S. R., & Prince, R. (1989). Firm incentives to promote technological change in pollution control. *Journal of Environmental Economics and Management*, *17*(3), 247–265. https://econpapers.repec.org/article/eeejeeman/v_3a17_3ay_3a1989_3ai_3a3_3ap_3a247-265.htm

Misiolek, W. S., & Elder, H. W. (1989). Exclusionary manipulation of markets for pollution rights. *Journal of Environmental Economics and Management*, *16*(2), 156–166. https://doi.org/10.1016/0095-0696(89)90006-5

Pototschnig, A. (1994). 'Economic instruments for the control of acid rain in Britain', in G. Klaassen and F. Forsunds (eds), *Economic Instruments for Air Pollution Control*, Dordrecht: Kluwer Academic Publishers.

Salop, S. C., & Scheffman, D. T. (1987). Cost-Raising Strategies. *The Journal of Industrial Economics*, *36*(1), 19–34. https://doi.org/10.2307/2098594

Sutton, J. (1998). Technology and market structure: theory and history. The MIT Press.

Voola, J. & Kilminster, D. (2003). Cost-reducing technology and Cournot competition, paper presented at the 2003 Econometric Society Australian Meetings, University of New South Wales, Sydney NSW, July

Voola, J. J. (2006). Technological change and industry structure: A case study of the petroleum industry. *Economics of Innovation and New Technology*, *15*(3), 271–288. https://doi.org/10.1080/10438590500149597