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98s-31

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Montréal
Octobre 1998

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ISSN 1198-8177

Collusive Allocation of Tradeable Pollution Permits[*]

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Résumé / Abstract

Nous montrons que dans une industrie oligopolistique, les firmes ont intérêt à utiliser le marché des permis de pollution comme moyen de coordonner leur taux de production. Si les firmes sont initialement identiques, le marché des permis de pollution peut créer une industrie avec des firmes asymétriques.

We show that when polluting firms are Cournot oligopolists, they may have an incentive to use the market of pollution permits as a means of indirectly coordinating their outputs. If firms are initially identical, trade in pollution permits may result in an asymmetric oligopoly. The case where firms are initially asymmetric is also considered.

Mots Clés : Permis de pollution, oligopole asymétrique

Keywords : Pollution permits, asymmetric oligopoly

JEL : L13, Q20

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1 Introduction

Many economists have argued that tradeable pollution permits are better than direct regulations that set rigid emission standards for all firms, because trade in pollution permits allow individual firms to choose their pollution levels that suit firm-specific demand and cost conditions that are typically private information.[1] Several authors, however, have pointed out that large firms may have an incentive to manipulate the permits market. Misiolek and Elder (1987) point out that a dominant firm my buy permits to raise rivals' costs. Newbery (1990, pp. 344-45) considers a Cournot oligopoly with two identical firms; he shows numerically that, for a given number of permits, under certain parameter values, aggregate profit is minimized (but social welfare is maximized) if both firms hold the same amount of permits. This indicates that firms have an incentive to trade in permits, possibly at the expense of social welfare. Von der Fehr (1993) shows that monopolization of the product market may occur via trade in permits. Sartzetakis (1996) also considers permit trading, but imposes asymmetry by assuming that one firm has price setting power in the permits market.

In this paper we show that whether oligopolistic firms have an incentive to trade in permits depends on the degree of convexity of the function relating unit production cost to emission level. If this function is concave (or not 'too' convex), then firms will trade in permits so as to create significant asymmetry in an ex-ante symmetric industry. By not restricting to linear demand, we obtain a general characterization of the nature of the solution. In particular, Newbery's example is shown to belong to a subset of cases that we consider. Even if firms are initially identical, their collusive behaviour in the allocation of pollution permits among themselves may result in an asymmetric distribution of permits. This is because the resulting cost asymmetry among firms will increase industry profit. This phenomenon of"unequal treatment of equals" is a special feature of a class of problems involving a two-stage (or multi-stage) game among oligopolists who are rivals in the last stage.[2] The case where firms are initially asymmetric will also be considered.

[1]For some recent contributions to the literature on pollution permits, see Milliman and Prince (1989), von de Fehr (1993), Sartzetakis (1996). For Pigouvian taxes and standards, see Baumol and Oates (1988) and Barnett (1980).

[2]See Salant and Shaffer (1972, 1996). Long and Soubeyran (1997c) show that an increase in the variance of the distribution of marginal costs will enhance industry profit. For a more general treament, and applications, Long and Soubeyran (1997a, 1997b).

2 The Model

We consider an oligopoly consisting of n firms with non-identical cost functions. They produce a homogenous final good. The production process generates pollutants. A pollution permit allows a firm to emit one unit of pollutant per period. We assume that e_i, the amount of pollutant emitted by firm i, is an increasing function of its output level and a decreasing function of of its stock of abatement equipment A_i. We write $e_i = f_i(q_i, A_i)$. Thus, given A_i, if firm i wants to produce the quantity q_i of output, the amount of pollution permits that firm i needs is $e_i = f_i(q_i, A_i)$. Assume that this function can be inverted to give $A_i = a_i(e_i)v(q_i)$, where $a_i'(e_i) < 0$ and $v'(q_i) > 0$. This means that, for a given q_i, the more pollution permits the firm has, the smaller is the necessary stock of abatement equipment. We also assume that, in addition, there is a raw material cost $b_i > 0$ per unit of output. The total cost of producing q_i is then $b_i q_i + a_i(e_i)v(q_i)$.

We consider a three stage game. In stage 1, the oligopolists collectively lobby with the regulator to obtain e^0 permits per firm. The greater is the lobbying effort, the greater is e^0. We represent this by a lobbying cost function $\phi(ne^0)$ with $\phi' > 0$. An alternative interpretation is that the oligopolists collectively purchase pollution permits from the open market, and the cost of the total purchase of ne^0 units is $\phi(ne^0)$ which may or may not be a linear function, because their purchase may affect the market price of the permits[3].

In stage 2, each oligopolist buys (or sells) permits from other oligopolists. Even if firms are ex-ante identical and have the same endowment of permits, they may have an incentive to trade, because by redistributing permits unevenly accross firms, the oligopolists are able to alter the distribution of marginal costs. We have shown elsewhere[4] that for any given marginal cost sum C, an increase in the dispersion of marginal costs (as measured by the variance), will increase aggregate profits, because while aggregate production and hence price remain constant, the aggregate production cost falls due to the increase in the market shares of lower cost firms. However, for a given number of permits, reallocations of permits may change the marginal cost sum C. Another way of putting this is: for a given marginal cost sum, a redistribution of that sum may necessitate further purchase of permits, which may be very costly. Therefore, whether firms will end up with an asymmetric allocation of permits depends on the degree of convexity of the function

[3]Clearly this model can be re-interpreted, with suitable modifications, as one of collective purchase of an intermediate input.

[4]See Long and Soubeyran (1997c).

$\phi(ne)$ and of the relationship between emissions and reduction in unit production cost.

The last stage of the game begins after the permits have been traded among firms. Cournot rivalry in the product market gives equilibrium profits as described below.

Let $P(Q)$ denote the inverse demand function, where $P' \leq 0$. Given e_i, firm i's marginal cost of production is $b_i + a_i(e_i)v'(q_i)$ Then, if $\hat{Q}$ is the Cournot equilibrium industry output[5], firm i's *equilibrium* output satisfies

$$\hat{q}_i P'(\hat{Q}) + P(\hat{Q}) = b_i + a_i(e_i)v'(\hat{q}_i) \equiv \theta_i \tag{1}$$

where θ_i is firm i's marginal cost at a Cournot equilibrium. The usefulness of our definition

$$\theta_i = b_i + a_i(e_i)v'(\hat{q}_i) \tag{2}$$

will become clear as we proceed.

Summing (1) over all firms, we have

$$\hat{Q}P'(\hat{Q}) + nP(\hat{Q}) = n\theta_N$$

where $\theta_N \equiv (1/n)\sum_{i\in N}\theta_i$. Hence $\hat{Q}$ is a function of θ_N and is independent of its components[6], the θ_i's.

$$\hat{Q} = \hat{Q}(\theta_N) \tag{3}$$

and firm i's equilibrium output is

$$\hat{q}_i = \frac{P(\hat{Q}(\theta_N)) - \theta_i}{[-P'(\hat{Q}(\theta_N))]} \equiv \hat{q}_i(\theta_i, \theta_N) \tag{4}$$

It follows from (2) and (4) that for a given θ_N, there is a one-to-one relationship between the firm's quantity of pollution permits e_i and its marginal cost θ_i:

$$a_i(e_i) = \frac{\theta_i - b_i}{v'[\hat{q}_i(\theta_i, \theta_N)]} \tag{5}$$

In equibrium, firm i's abatement cost is

$$a_i(e_i)v(\hat{q}_i) = \frac{[\theta_i - b_i]\hat{q}_i}{\eta(\hat{q}_i)}$$

[5]For the existence of a Cournot equilibrium, see Gaudet and Salant (1991). We assume that our demand and cost functions satisfy their sufficient conditions for existence and uniqueness.

[6]This generalizes the result of Bergstrom and Varian (1985a,b) where they assume constant marginal cost.

where $\eta(q_i)$ is defined as the elasticity of $v(q_i)$: $\eta(q_i) = q_i v'(q_i)/v(q_i)$.

Equilibrium profit of firm i is

$$\hat{\pi}_i = \hat{q}_i\{\hat{P} - b_i\} + \{(\hat{P} - \theta_i) - (\hat{P} - b_i)\}[\hat{q}_i/\eta(\hat{q}_i)]$$

Using $\hat{P} - \theta_i = \hat{q}_i \hat{P}'$, we can expressed equilibrium profit as

$$\hat{\pi}_i = (\hat{P} - b_i)\left[1 - \frac{1}{\eta\left(\hat{q}_i\right)}\right]\hat{q}_i + [-\hat{P}']\frac{\hat{q}_i^2}{\eta(\hat{q}_i)} \tag{6}$$

Industry profit in equilibrium is

$$\hat{\Pi} = \sum_i \hat{\pi}_i = [-\hat{P}']\hat{H} + \sum_i (\hat{P} - b_i)\left[1 - \frac{1}{\eta\left(\hat{q}_i\right)}\right]\hat{q}_i \tag{7}$$

where $\hat{H}$ is a "modified Herfindahl index" of concentration:

$$\hat{H} = \sum_{i \in N} \frac{\hat{q}_i^2}{\eta(\hat{q}_i)}$$

From (7), if $\eta\left(\hat{q}_i\right) = 1$, which is the case if $v(q_i) = q_i$, then, keeping total industry output constant, industry profit is an increasing function of the Herfindahl index of concentration:

We now turn to stage 2 of the game, where firms buy or sell permits to each other. In what follows, we consider only the case where $v(q_i) = q_i$, for simplicity. In this case, from (2), with $v' = 1$ identically, we can write $\theta_i = \theta_i\left(e_i\right)$, and the equilibrium gross profit of firm i in the last stage is

$$\hat{\pi}_i = \hat{\pi}_i[\theta_i(e_i), n\theta_N(\mathbf{e})] = [\hat{P} - \theta_i]\hat{q}_i(\theta_i(e_i), \theta_N(\mathbf{e}))$$

where

$$\theta_N(\mathbf{e}) = \frac{1}{n}\sum_{i \in N} \theta_i(e_i)$$

If no firm buys or sells permits, then firm i's net profit is

$$V_i^0 = \hat{\pi}_i[\theta_i(e^0), \theta_N(\mathbf{e}^0)] - \frac{1}{n}\phi(ne^0)$$

Firm i has incentives to trade in permits if after trade it earns a profit (inclusive of the revenue R_i it gets from the sale of some or all of its permits) that exceeds V_i^0. Define

$$V_i(e_i, \mathbf{e}) = \hat{\pi}_i[\theta_i(e_i), \theta_N(\mathbf{e})] - \frac{1}{n}\phi(ne^0)$$

We assume that trading takes the form of the Nash bargaining game[7] and that its outcome maximizes the Nash product Z

$$Z = \Pi_{i \in N} \left[V_i(e_i, \mathbf{e}) + R_i - V_i^0 \right] \tag{8}$$

where the maximization is with respect to $(e_1, ..., e_n) = \mathbf{e}$ and $(R_1, ..., R_n) = \mathbf{R}$, subject to the following constraints

$$\sum_{i \in N} R_i = 0$$

$$V_i(e_i, \mathbf{e}) + R_i \geq V_i^0$$

$$\sum_{i \in N} e_i = ne^0 \tag{9}$$

Clearly, if $(\mathbf{e}^*, \mathbf{R}^*)$ is the solution of this maximization problem then, given $\mathbf{e}^*$, the optimal $\mathbf{R}^*$ must satisfy the following conditions

$$R_i^* = -V_i(e_i, \mathbf{e}) + V_i^0 + \frac{1}{n} \sum_{k \in N} \left[V_k(e_k, \mathbf{e}) - V_k^0 \right] \tag{10}$$

This condition implies that each firm's net profit (including the net receipt R_i) must exceed its status quo profit V_i^0 by a fraction $1/n$ of the net surplus caused by the redistribution of permits. Substitute (10) into (8) to obtain

$$Z = \left(\frac{1}{n} \right)^n \left[\sum_{i \in N} \left[V_k(e_k, \mathbf{e}) - V_k^0 \right] \right]^n$$

It follows that the optimal $\mathbf{e}^*$ must maximize

$$\sum_{k \in N} \left[V_k(e_k, \mathbf{e}) - V_k^0 \right] \equiv W$$

subject to (9). This is to be expected as aggregate surplus,W, must be maximized in our cooperative bargaining problem.

Let's denote by $\mathbf{e}^*(e^0)$ the allocation of permits that results from this bargaining problem. In Stage 1 of the game, the firms collectively choose e^0 and together they incur the lobbying cost $\phi(ne^0)$:

$$\max_{e^0} \sum_{i \in N} [V_i(e_i^*(e^0), \mathbf{e}^*(e^0)) - V_k^0] - \phi(ne^0)$$

[7] See Binmore et al. (1986).

Instead of solving this problem recursively, knowing the solution $e_i^*(e^0)$ of the Stage 2's problem, it turns out to be more convenient to solve the problems of Stage 1 and Stage 2 as a combined problem.

Let us assume that

$$a_i(e_i) = a_i^0 - r_i(e_i)$$

where $r_i(e_i)$ can be interpreted as the reduction in firm i's unit cost of production if the firm has e_i permits. This function is assumed to be defined over a compact range $[0, e_i^{\max}]$. Assume $r_i(0) = 0$ and $r_i'(e_i) > 0$, for $0 \leq e_i \leq e_i^{\max}$ with $r_i(e_i^{\max}) = r_i^{\max} \leq a_i^0$. Inverting the function to get $e_i = e_i(r_i)$ where $0 \leq r_i \leq r_i^{\max}$. Then $\theta_i = b_i + a_i^0 - r_i$ and $\theta_N = b_N + a_N - r_N$ where

$$b_N = \frac{1}{n}\sum_{i\in N} b_i, \quad a_N = \frac{1}{n}\sum_{i\in N} a_i, \quad r_N = \frac{1}{n}\sum_{i\in N} r_i$$

Note that the Cournot equilibrium industry output is $\hat{Q} = \hat{Q}(n\theta_N) = \hat{Q}(r_N)$ (with a slight abuse of notation.)

The combined problem for Stage 1 and Stage 2 becomes: Find $r_i \in [0, r_i^{\max}]$, $i \in N$, to maximize the net profit of the industry (knowing that firms will be Cournot rivals in Stage 3)

$$\pi^{net} = \frac{1}{[-P'(\hat{Q}(r_N))]}\sum_{i\in N}\left[\hat{P} - b_i - a_i^0 + r_i\right]^2 - \phi(\sum_{i\in N} e_i(r_i)). \tag{11}$$

We propose to solve problem (11) by using a *two-step procedure.* In the first step, we fix r_N and maximize π^{net} with respect to $(r_1, ..., r_n)$ subject to the constraints $r_n = (1/n)\sum_{i\in N} r_i$ and $r_i \in [0, r_i^{\max}]$. In the second step, we choose r_N. The merit of this procedure is that in the first step, because r_N is fixed, the Cournot equilibrium industry output is fixed, and so is the price $\hat{P}$. This allows us to focus on the cost minimization consideration: on the one hand, there is production and abatement costs as reflected in the first term on the right-hand side of (11); on the other hand, there are the lobbying costs in the second term on the right-hand side of (11).

The first step:

Given r_N, define the feasible set $S(r_N)$ by

$$S(r_N) = \{(r_1, ..., r_n) : 0 \leq r_i \leq r_i^{\max}, \sum_{i\in N} r_i = nr_N\}$$

Define the vector $\mathbf{r}^{\Box}$ by $\mathbf{r}^{\Box} = (r_1^{\Box}, ..., r_n^{\Box})$ where $r_i^{\Box} \equiv b_i + a_i^0 - \hat{P}$. Let $f(\mathbf{r}) \equiv \phi(\sum_{i \in N} e_i(r_i))$. Then, given r_N, the objective function (11) becomes

$$\max_r \psi(\mathbf{r}) \equiv \frac{1}{[-P'(\hat{Q}(r_N))]} \|\mathbf{r} - \mathbf{r}^{\Box}\|^2 - f(\mathbf{r}) \tag{12}$$

where $\|\mathbf{r} - \mathbf{r}^{\Box}\|^2$ is the Euclidean distance between the vector $\mathbf{r}$ (to be chosen from the feasible set $S(r_N)$) and the fixed vector $\mathbf{r}^{\Box}$. This term is strictly convex in $\mathbf{r}$.

We will first consider the case of ex ante identical firms.

Proposition 2.1 (Ex ante identical firms)

(i) If $f(\mathbf{r})$ is sufficiently convex so that $\psi(\mathbf{r})$ is strictly concave, then given any $r_i \in [0, r^{\max}]$, the solution is symmetric: $r_i = r_N$ for all $i \in N$.

(ii) If If $f(\mathbf{r})$ is concave (or not too convex) so that $\psi(\mathbf{r})$ is strictly convex, then the solution is at a corner of the set $S(r_N)$. This implies that ex ante identical firms are treated as unequals.

(iii) If $\psi(\mathbf{r})$ is neither concave nor convex, then there may exist several solutions in the interior of $S(r_N)$.

Proof: See Long and Soubeyran (1997a).$\Box$

Next, consider the case of ex ante non-identical firms. For simplicity we assume that the function $\phi(.)$ is linear, so that $f(\mathbf{r}) = \sum_{i \in N} e_i(r_i)$. For given r_N, define

$$\psi_i(r_i) = \frac{1}{[-P'(\hat{Q}(r_N))]} [\hat{P} - b_i - a_i^0 + r_i]^2 - e_i(r_i)$$

We assume that $\psi_i(r_i)$ is strictly concave. This assumption means that the functions $e_i(r_i)$ are very convex. In economic terms, this implies that additional permits do not significantly reduce cost. Define $y_i = \psi_i'(r_i)$ and $\bar{y}_i = \psi_i'(r_i^{\max})$. Without loss of generality, let $\bar{y}_1 \le \bar{y}_2 \le \bar{y}_3 ... \le \bar{y}_n$. We will assume that the heterogenous firms are not too different from each other, in the following sense:

$$\max\{\psi_j'(r_j^{\max})\} < \min\{\psi_i'(r_i)\} \tag{13}$$

We obtain the following results:

Proposition 2.2 (Ex ante non-identical firms)

If at the optimum all firms own some permits (i.e., $r_i > 0$ for all $i \in I$), then, under assumption (13), there exists an integer $m^+ \le n$ such that at the optimum, all firms in the set $\bar{M} = \{m^+ + 1, ..., n\}$ achieve $r_i^{\max}$, and the remaining firms achieve $r_i^* = (\psi_i')^{-1}(\lambda)$ where λ and m^+ satisfy the following conditions

$$\sum_{i \in M^+} (\psi_i')^{-1}(\lambda) = n r_N - \sum_{k \in \bar{M}} r_k^{\max}$$

$$\bar{y}_{m^+} \leq \lambda < \bar{y}_{m^++1}$$

Proof: see the Appendix.□

The second step:

In the second step we determine r_N^*. Since this involves no new feature, to save space we will not report the computation here.

3 Concluding remarks

In this paper, we have shown that tradeable pollution permits can be used by oligopolists as a means of indirectly coordinating their outputs so as to maximize industry profit, at the expense of the consumers. Often, because of anti-trust laws, firms cannot form a cartel to allocate outputs among themselves. They therefore have an incentive to engage in trade in pollution permits as an indirect method of conducting anti-competitive behaviour.

Our analysis suggests that from the point of view of efficient allocation of resources, pollution standards or the classical Pigouvian tax may be superior to tradeable pollution permits, given that firms are oligopolists.

APPENDIX

Proof of Proposition 2.2

We use the approach developed in Luenberger (1969) and Rockafellar (1970). The Lagrangian is

$$L = \lambda \left[nr_N - \sum_{i \in N} r_i \right] + \sum_{i \in N} \psi_i(r_i) + \sum_{i \in N} \mu_i r_i + \sum_{i \in N} \gamma_i \left[r_i^{\max} - r_i \right]$$

The necessary conditions are:

$$\frac{\partial L}{\partial r_i} = y_i - \lambda + \mu_i - \gamma_i = 0$$

$$\mu_i r_i = 0, \quad \mu_i \geq 0, \quad r_i \geq 0$$

$$\gamma_i \left[r_i^{\max} - r_i \right] = 0, \quad \gamma_i \geq 0, \quad \left[r_i^{\max} - r_i \right] \geq 0$$

Thus (i) if $r_i = 0$, then $\psi_i'(0) - \lambda + \mu_i = 0$, (ii) if $r_i = r_i^{\max}$, then $\psi_i'(r_i^{\max}) - \lambda - \gamma_i = 0$ and (iii) if r_i is an interior solution, then $\psi_i'(r_i) = \lambda$. Clearly, for any pair (i, j) such that $\psi_j'(r_j^{\max}) < \psi_i'(0)$, it is not possible that $r_i = 0$ and $r_j = r_j^{\max}$.

Let

$$\bar{M} \equiv \{ i \in N : r_i^* = r_i^{\max} \}$$

$$M^+ \equiv \{ i \in N : 0 < r_i^* < r_i^{\max} \}$$

$$M^0 \equiv N \backslash (M^+ \cup \bar{M}) = \{ i \in N \mid r_i = 0 \}$$

Assume that

$$\max\{ \psi_j'(r_j^{\max}) \} < \min\{ \psi_i'(0) \}.$$

In economic terms, this assumption means that the heterogenous frms are not too different from each other. This assumption ensures that M^0 is an empty set. We now characterize the optimum such that M^0 is empty (the case where M^0 is not empty can be analyzed similarly). Define $\rho_i(\lambda) = (\psi_i')^{-1}(\lambda)$, and let

$$\Omega(\lambda) \equiv \sum_{i \in M^+} (\psi_i')^{-1}(\lambda) \equiv \sum_{i \in M^+} \rho_i(\lambda)$$

Then

$$\Omega(\lambda^*) = nr_N - \sum_{j \in \bar{M}} r_j^{\max}$$

Note that λ^* is unique because $\Omega(\lambda)$ is strictly decreasing (as $\rho_i'(\lambda) = 1/\psi_i''(r_i) < 0$).We can rank the $\bar{y}_i \equiv \psi_i'(r_i^{\max})$ as follows

$$\bar{y}_1 < \bar{y}_2 < \ldots < \bar{y}_{m^+} < \bar{y}_{m^+ + 1} < \ldots < \bar{y}_n$$

where m^+ satisfies

$$\bar{y}_{m^+} < \lambda^* = \Omega^{-1}\left(nr_N - \sum_{j \in \bar{M}} r_j^{\max}\right) < \bar{y}_{m^+ + 1}$$

Then

$$r_i^* = (\psi_i')^{-1}\left[\Omega^{-1}\left(nr_N - \sum_{j \in \bar{M}} r_j^{\max}\right)\right] \quad , i \in M^+$$

$$r_j^* = r_j^{\max} \quad , j \in \bar{M}$$

(Note that if the conjugate function of ψ_i is denoted by ψ_i^*, where

$$\psi^*(\lambda) = \sup_{r_i}[\psi(r_i) - \lambda r_i]$$

then $(\psi_i')^{-1} = \psi_i^{*\prime}$

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