Tradable Emission Rights and Strategic Interaction

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Abstract. The use of tradable emission rights as environmental policy instruments may affect the conditions for strategic interaction between regulated firms and thus have implications for competition policy. This paper presents an analysis of how, and under what conditions, emission rights can be used strategically by oligopolistic firms for predatory and exclusionary purposes.

Key words. Tradable emission rights, imperfect competition, oligopoly, strategic interaction, predation.

1. Introduction

The use of economic instruments in the form of tradable emission rights or pollution permits[1] have become increasingly popular as a means of implementing reductions in environmental damage (Tietenberg, 1990). By bringing such externalities under control of the price system, potentially, pollution permits can achieve specified levels of environmental quality in an efficient manner. Indeed, it has been shown by W. David Montgomery (1972) that under certain conditions, notably including perfect competition, tradable emission rights will reduce pollution to given standards at least cost to the regulated industry.

Many industries, however, do not come near the ideal of perfect competition, and when competition is imperfect, one may ask how firms might manipulate permit markets to their own advantage. The question of how a single firm with market power in a market for transferable property rights can exercise its influence to minimize the financial burden from pollution regulation is studied by Robert W. Hahn (1984). He shows how a firm which elects to buy (sell) pollution permits will act similarly to a monopsonist (monopolist); it will tend to buy (sell) too few pollution permits relative to the efficient solution in order to depress (raise) the permit price. The end result is that total expenditure on abatement will exceed its cost-minimizing level.

In addition to anti-competitive behaviour in the permit market, there may also be exclusionary manipulation of emission rights by firms to influence the behaviour of rivals in the same industry. One study of this question is by Walter S. Misiolek and Harold W. Elder (1988) who analyze a dominant firm facing a fringe of price-taking competitors. Their main conclusion is that

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the dominant firm will manipulate the pollution permit market in order to drive up the cost to the fringe (see also Salop and Scheffman, 1983). The authors note that, depending on the initial distribution of permits, this strategic effect can sometimes worsen and sometimes ameliorate the abatement inefficiency identified by Hahn.

With the exception of the Misiolek-Elder study there seems to have been no explicit analysis of oligopolistic rivalry in the presence of tradable pollution permits, even though it has been realized that emission rights may become a vehicle for anti-competitive conduct. Part of the reason for this may be the view put forward by some authors that such exclusionary strategic behaviour often will not be important (Tietenberg, 1985, 1990). There are, however, examples where this is very implausible, one prominent case being the U.K. electricity industry. This industry consists of one publicly owned nuclear-based producer and two privately owned firms which are responsible for the bulk of U.K. emissions of sulphur dioxide (as well as contributing to other types of pollution). If the programme to reduce emissions from this industry is to be based on tradable pollution permits strategic interaction obviously becomes an important issue (Newbery, 1990; Vickers and Yarrow, 1991 section 8).

Even though strategic manipulation may be of concern in the U.K. electricity case, market power issues are probably of limited importance for most air pollution control programs since typically the number of sources is large (Maloney and Yandle, 1984; Tietenberg, 1985).[2] Strategic manipulation is most likely to become a problem in more localized permit markets, and therefore it may be a more important aspect of water pollution control than of air pollution control.[3] For example, Nick Hanley and Ian Moffat (1992) suggest that, for the Forth Estuary in Scotland, market power may become a serious obstacle for least-cost pollution control based on tradable permits.[4]

While we would not wish to overemphasize the market power problem, there would appear to be a need to fill the gap in the literature on tradable emission rights and oligopolistic interaction. This paper attempts to do so by presenting an analysis of a duopoly model of two symmetric firms competing as Cournot quantity setters.[5] Firms can buy emission rights in a market in which they both have market power. The number of emission rights obtained by a firm determine its operational costs (net of expenditure on permits).

The first question studied is whether pollution permits are likely to become an instrument for monopolisation (and entry deterrence) in such a market. It is shown that in a wide range of circumstances, in particular when products are fairly close substitutes and diseconomies of scale are not prevalent, industry profits will be maximized when all permits are concentrated in one firm. It follows that emission rights can serve as an ideal instrument for monopolisation (if this is not prevented by competition policy) by making it profitable to pay competitors to leave the market while at the same time providing the necessary means to keep new firms from entering. Typically such an industry structure is detrimental to consumer welfare, and indeed overall industry welfare (as measured by the sum of profits and consumer surplus), and conditions are given for when this occurs.

Complete monopolisation requires that pollution permits are essential for profitable operations, i.e. abatement costs are substantial, and furthermore, that the supply of permits is inelastic. If the residual supply curve for permits facing the industry (i.e. net of demand of firms in other industries) is elastic, complete monopolisation may not be possible, but there will still be scope for strategic manipulation of the permit market. There are two main channels through which such strategic use of emission rights may be exercised. First, the number of permits bought determines a firm's cost structure and hence it's strategic position. Second, manipulation of the permit price affects rivals' costs. It is shown that strategic considerations typically strengthen incentives for investment in pollution permits. Such overinvestment reduces marginal production costs and makes firms more aggressive. At the same time overinvestment, by driving up the price of pollution permits, increases the marginal costs of rivals. The extent to which firms may want to alter their technology choice (capacity, input choice etc.) to enhance the strategic effect of emission rights, is also investigated. In particular, it is shown that the typical outcome will involve firms underinvesting in abatement equipment in order to become more aggressive in the market for emission rights.

The rest of the paper is devoted to a formal analysis of the propositions referred to above. All proofs are relegated to an appendix.

2. Monopolisation

Can firms in an industry benefit from trading emission rights amongst themselves, and, if so, how will such trade affect industry structure and economic welfare? A necessary condition for trade in permits is that the transactions raise the total profits of the buying and selling firms. This section therefore presents an analysis of how the combined equilibrium profits of otherwise identical firms vary as emission rights are reallocated between them, extending and generalizing an example considered by David M. Newbery (1990) (see below). Thus, rather than considering the actual trading process, I investigate the potential for trade by establishing the conditions under which Pareto-improving reallocations of permits are possible. It is shown that there is scope for profitable exchange of permits for a wide range of model parameter values and that a completely asymmetric industry structure — monopoly — may result if trade is allowed. Consumer surplus will typically fall as the industry structure becomes more monopolized, although the overall welfare consequences (as measured by the sum of profits and consumer surplus) are ambiguous.[6]

Two symmetric Firms 1 and 2 compete as Cournot quantity setters. To make the analysis as general as possible, I start off by assuming very general profit expressions. (Specific examples will be considered in later sections.) Thus profits, gross of any costs of obtaining emission rights, are given by:

$$\Pi(Q; X, q) = r(Q; q) - c(Q; X), \text{ and} \tag{1}$$

$$\pi(q; x, Q) = r(q; Q) - c(q; x), \tag{2}$$

where $r(\cdot)$ is gross revenue, $c(\cdot)$ is total cost, and Π (π) is the profit, Q (q) the output and X (x) the number of emission rights of Firm 1 (2).[7] The cost and revenue functions are assumed twice continuously differentiable.[8] Furthermore, it is assumed that $r_1 > 0$, $r_2 < 0$, $c_1 > 0$, and $c_2 < 0$.

A given number of emission rights, normalized to 1, is allocated to the industry in proportions X and $1 - X$ to Firms 1 and 2 respectively, i.e. $x = 1 - X$. Assume (without loss of generality) $X \geqslant 1/2$ and call 1 the large and 2 the small firm.[9]

Necessary and sufficient conditions for a stable interior Nash equilibrium $(Q^*(X), q^*(X))$ are

$$\Pi_Q = \pi_q = 0, \text{ and} \tag{3}$$

$$\Pi_{QQ} < 0, \pi_{qq} < 0, \Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ} > 0. \tag{4}$$

If X is such that $\pi(q; 1 - X, Q^M(X)) < 0$ for all q, where $Q^M(X)$ is monopoly output, Firm 2 stays out of the market and Firm 1 operates as a monopolist, i.e., $Q^*(X) = Q^M(X)$ and $q^*(X) = 0$. Define $\Phi(X) \equiv \Pi(Q^*(X); X, q^*(X)) + \pi(q^*(X); 1 - X, Q^*(X))$ as total (equilibrium) industry profits.

I want to consider how $\Phi(X)$ varies with X. In particular, the effect on industry profits of a (small) reallocation of emission rights from the smaller to the larger firm may be approximated by:[10]

$$\Phi'(X) = \Pi_X - \pi_x + \Pi_q \cdot \frac{dq}{dX} + \pi_Q \frac{dQ}{dX} \tag{5}$$

by the envelope theorem. Thus, there are two effects of a reallocation of emission rights; direct cost savings (represented by the first two terms); and output adjustments.

Cost savings are more likely to be positive if Π_X and π_x (i.e. $-c_2$) are increasing in output, in particular, if marginal costs are decreasing in the number of emission rights, i.e. $c_{12} < 0$ or $\Pi_{QX}, \pi_{qx} > 0$. On the other hand, since the larger firm already has more emission rights, one has to take into account the signs of Π_{XX} and π_{xx} (i.e. $-c_{22}$) as well, which are likely to be negative. Thus, the overall direct effect on costs is uncertain. It can be shown that if products are homogeneous and the cost function is homogeneous of degree 1 in output and emission rights, i.e. $c(\gamma\tilde{q}; \gamma\tilde{x}) = \gamma \cdot c(\tilde{q}; \tilde{x})$, then the direct effect of reallocating emission rights to the larger firm is to increase total costs.[11] However, as demonstrated below, in other examples where scale economies are sufficiently prevalent, total industry costs will be decreasing as the industry becomes more asymmetric.

The effects on outputs can be found by differentiating the first-order conditions for the Cournot equilibrium and solving:

$$\frac{dQ}{dX} = -\frac{\pi_{qq}\Pi_{QX} + \Pi_{Qq}\pi_{qx}}{\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ}}, \text{ and}$$

$$\frac{dq}{dX} = \frac{\Pi_{QQ}\pi_{qx} + \pi_{qQ}\Pi_{QX}}{\Pi_{QQ}\pi_{qq} - Q_{Qq}\pi_{qQ}}. \tag{6}$$

Sufficient conditions for $dQ/dX > 0$ and $dq/dX < 0$ are (a) $\Pi_{QX}, \pi_{qx} > 0$ and (b) $\Pi_{Qq}, \pi_{qQ} < 0$, $i = 1, 2$. As already noted, (a) is satisfied if more emission rights reduce marginal costs. Furthermore, (b) holds if outputs are strategic substitutes.[12] For most realistic examples one would expect these conditions to be satisfied and, thus, following the reallocation of emission rights, the larger firm to increase its output at the expense of the smaller firm.

Further insight on the effects on firm outputs may be gained by rewriting the output terms as

$$\Pi_q \cdot \frac{dq}{dX} + \pi_Q \cdot \frac{dQ}{dX} = [\Pi_q - \pi_Q] \cdot \frac{dq}{dX} + \pi_Q \cdot \left[\frac{dQ}{dX} + \frac{dq}{dX}\right]. \tag{7}$$

The output adjustment term can be decomposed into two sub-effects; output reallocation and aggregate output change. Note that $\Pi_q - \pi_Q = r_2(Q; q) - r_2(q, Q)$. Hence, if one assumes that a more asymmetric allocation of emission rights leads to an increasingly asymmetric market structure ($dQ/dX > 0$ and $dq/dX < 0$), sufficient conditions for the reallocation effect to be non-negative are $r_{12} \leqslant 0$ and $r_{22} \geqslant 0$. When inverse demand functions are linear, this is indeed the case. Consequently, in many cases we expect this condition to hold, and thus the output reallocation effect, ceteris paribus, to increase industry profits. Furthermore, if total output is reduced, which it will be for most reasonable specifications of demand and cost functions, the aggregate-output effect also tends to increase profits.

Combining the direct cost and the output effects, we conclude that for a wide range of parameter values industry profits are increasing as industry structure becomes more asymmetric. In other words, there are profitable exchanges of emission rights between the two duopolists which leave each better off than in the symmetric equilibrium. Indeed, under fairly general conditions industry profits are maximized by monopoly, implying that it pays one firm to buy all the permits in order to become an unconstrained monopolist. Sufficient conditions for such an outcome to occur are given in the following proposition:[13]

PROPOSITION 1. Industry profits will be maximized at $X = 1$ if (i) products are homogeneous, (ii) the cost function is sub-additive in outputs and emission rights, i.e. $c(\tilde{q} + \hat{q}; \tilde{x} + \hat{x}) \leqslant c(\tilde{q}; \tilde{x}) + c(\hat{q}; \hat{x})$, and (iii) emission rights are essential for profitable operation, in particular, $\forall q$, $r(q, Q^M(1)) < c(q; 0)$ where $Q^M(1)$ is the monopoly output when all emission rights are allocated to the monopolist.

We may conclude that environmental regulation based on tradable (or auctioned) emission rights may create an instrument for industry monopolisation. Note that the type of argument underlying this conclusion is basically similar to that of the study of incentives for mergers. In particular, in the absence of entry threats, the merger of two duopolists will be profitable if technology and demand conditions are such that industry profits are maximized by monopoly. However, in general mergers are vulnerable if the resultant (temporary) softening of competition leads to the entry of new firms. This is different when monopolisation occurs via the permits market. Pollution permits introduce an instrument for monopolisation (where none previously existed) firstly because there may be profitable exchanges of permits between existing firms that lead to exits, *and*, secondly, because emission rights provide a means for blockading entry by new firms. Of course, if complete monopolisation is not allowed by competition policy, firms may aim at the maximum allowable degree of asymmetry.

Monopolisation is less likely when emission rights are not essential for profitable operation, cost functions exhibit diseconomies of scale, or products are differentiated. To explore these possibilities further as well as to resolve the ambiguities revealed in the general discussion above, we will consider a specific example.

2.1. AN EXAMPLE

The specific functional forms assumed in this section generalize the example considered by Newbery (1990). Marginal operating costs, ignoring pollution abatement, equal $\beta + \alpha\tilde{q}$, where $\tilde{q}$ is output. β is set equal to zero without loss of generality and $\alpha \geqslant 0$. The amount of pollution released when output is $\tilde{q}$ and abatement equipment h in installed is $\tilde{q}/h$. The unit cost of abatement equipment is $\rho < 0.5$. Costs may then be written

$$c(\tilde{q}; \tilde{x}) = \frac{\rho}{\tilde{x}} \cdot \tilde{q} + \frac{\alpha}{2} \cdot \tilde{q}^2. \tag{8}$$

Inverse demand functions are assumed linear and given by

$$\begin{aligned} P &= 1 - b \cdot Q - c \cdot q, \\ p &= 1 - b \cdot q - c \cdot Q, \end{aligned} \tag{9}$$

where P (p) is the product price of the larger (smaller) firm and b and c are positive constants, and $b \geqslant c$.

Consider first the case when products are homogeneous ($b = c$) and marginal operating costs, ignoring pollution abatement, are constant ($\alpha = 0$) (this is the Newbery case). This model satisfies the assumptions of Proposition 1, so industry profits will be maximized at monopoly. Moreover, as noted above, with linear inverse demand functions quantities are strategic substitutes and hence the output reallocation effect is positive. In addition total output is decreasing in X. Therefore, since both the reallocation and industry output effects are positive, the overall effect of output adjustments is to increase industry profits. In this example the output adjustment terms of (5) reduce to

$$\Pi_q \cdot \frac{\mathrm{d}q}{\mathrm{d}X} + \pi_Q \cdot \frac{\mathrm{d}Q}{\mathrm{d}X} = \frac{\rho[2X-1]}{9bX^2[1-X]^2}\left\{1 + \rho \cdot \frac{9[2X-1]^2 - 1}{4X[1-X]}\right\} \gtrless 0. \tag{10}$$

The corresponding cost saving terms are

$$\Pi_x - \pi_x = \rho \cdot \frac{2X-1}{X^2[1-X]^2}\left\{\rho \cdot \frac{3[2X-1]^2+5}{4X[1-X]} - 1\right\}. \tag{11}$$

As can be seen from (11), the direct effect is to reduce costs for a sufficiently asymmetric market structure, i.e. X close to $1 - \rho$. Further, cost savings are larger the more expensive is abatement equipment, and are always positive for ρ sufficiently large ($> 1/5$). Only if the unit cost of abatement is small and firms are of similar size will the direct effect of permit reallocations be that total costs increase.

Figure 1 displays a numerical example, which shows how total industry profits increase as the industry structure becomes more asymmetric. (For sufficiently large X, the smaller firm becomes unprofitable and the larger firm operates as a monopolist. The profitability of monopoly is of course increasing in the number of emission rights held by the monopolist.)

As noted in the previous section, monopolisation is less likely when cost functions exhibit diseconomies of scale, or products are differentiated. Consider first product differentiation, i.e. $b > c$. The following result demonstrates that when products are sufficiently differentiated, profitable exchanges of emission rights from an initial symmetric allocation do not exist:

RESULT 2. Let demand be given by (9) and the cost function by (8) where $\alpha = 0$. Then for all $\rho < [\sqrt{2} - 1]/[2\sqrt{2} - 1]$ (≈ 0.23) there exists $\bar{c} > 0$ such that for all $c \in [0, \bar{c})$, $\Phi(X)$ is maximized at $X = 0.5$.

Figure 2 displays a numerical example of the proposition in Result 2. As long as the smaller firm is operating, total industry profits are decreasing as the

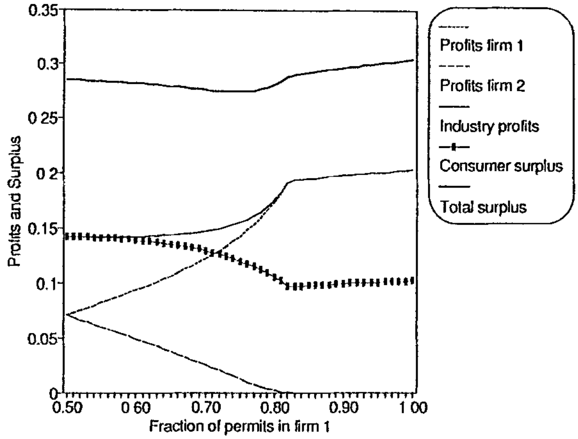

Fig. 1. Emission rights reallocation.
$b = c = 1, \rho = 0.1, \alpha = 0$.

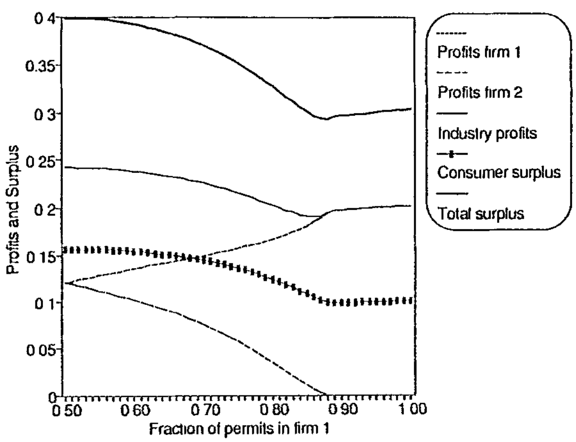

Fig. 2. Emission rights reallocation, differentiated products.
$b = 1, c = 0.3, \rho = 0.1, \alpha = 0$.

market structure becomes more asymmetric. For $X > 1 - \rho$ industry profits increase as more and more emission rights are allocated to the monopolist, but profits are still less at $X = 1$ than in the symmetric duopoly.

Consider next diseconomies of scale in marginal operating costs, i.e. $\alpha > 0$. In this example, one can show that whenever diseconomies of scale are sufficiently large industry profits are maximized in the symmetric equilibrium:

RESULT 3. Let the cost function be given by (8) and demand by (9) where

$b = c$. Then for all $\rho < [\sqrt{2} - 1]/[2\sqrt{2} - 1]$ there exists $\bar{\alpha}$ such that for all $\alpha > \bar{\alpha}$, $\Phi(X)$ is maximized at $X = 0.5$.

(Numerical examples would produce plots essentially similar to Figure 2.)

2.2. IMPLICATIONS FOR ECONOMIC WELFARE

We have seen that it will often be the case, in particular when products are not very differentiated and diseconomies of scale are not prevalent, that tradable emission rights provide a device for the monopolisation of an industry. Typically, we expect such a development to have adverse effects on consumer welfare, and, indeed, on overall economic welfare as measured by the sum of producer and consumer surplus. I discuss implications for economic welfare in light of the example developed in the preceding section.

If products are homogeneous, the inverse demand function is linear, and costs are given by (8) where $\alpha = 0$, total welfare as a function of X is given by

$$W(X) = \tag{12}$$

$$\begin{cases} \frac{1}{18b}\left\{2 - \frac{\rho}{X[1-X]}\right\}^2 + \frac{1}{9b}\left\{1 + \rho\frac{3X-2}{X[1-X]}\right\}^2 + \frac{1}{9b}\left\{1 + \rho\frac{1-3X}{X[1-X]}\right\}^2 & \text{if } 0.5 \leqslant X < 1-\rho \\ \frac{1}{8b}\left[1 - \frac{\rho}{X}\right]^2 + \frac{1}{4b}\left[1 - \frac{\rho}{X}\right]^2 & \text{if } 1-\rho \leqslant X \leqslant 1 \end{cases}$$

where the first part represents consumer surplus (C) and the latter the profits of Firm 1 and 2. (Remember that $X < 1 - \rho$ is the condition for positive profits of Firm 2.) For $X \in [0.5, 1 - \rho)$,

$$W'(X) = \frac{\rho}{9b}\,\frac{2X-1}{X^2[1-X]^2}\left\{\rho \cdot \frac{9[2X-1]^2 + 13}{2X[1-X]} - 4\right\}. \tag{13}$$

Note first that $W'(0.5) = 0$ (and $C'(0.5) = 0$). Furthermore, for sufficiently small ρ, total welfare is decreasing in X around $X = 0.5$. Thus for small ρ the positive effect on profits from a reallocation of emission rights between equally sized firms is outweighed by the negative effect on consumer welfare due to reductions in output. For large ρ the opposite is the case, the reason being the importance of economies of scale in cost savings on abatement equipment. For X sufficiently close to $1 - \rho$, $W' > 0$. We have the following result:

RESULT 4. Let demand and costs be as in (8–9), and assume $b = c$ and $\alpha = 0$. Then, when $\rho < (>)\ [4\sqrt{2} - 3\sqrt{3}]/[8\sqrt{2} - 3\sqrt{3}]$ (≈ 0.075), total welfare is maximized at $X = 0.5$ (1).

Figure 1 displays a numerical example. As can be seen, consumer surplus is smaller the more asymmetric is the duopoly market structure, and this effect is strong enough to make total welfare a decreasing function of X for $X \ll 1 - \rho$. However, as X approaches $1 - \rho$, i.e. when the smaller firm vanishes, the positive effect on profits outweighs the negative effect on consumer surplus. Furthermore, by allocating all permits to the monopolist, total welfare increases as the combined inefficiency of duopoly and the misallocation of emission rights is replaced by the single inefficiency of a monopoly.

If outputs are homogeneous, consumer surplus depends on total output only. On the other hand, if outputs are differentiated, consumer surplus will be affected by output reallocations even if aggregate output remains constant. Thus, we expect the welfare consequences to be even worse when products are differentiated (see Figure 2). Similarly, diseconomies of scale, by reducing the profit gains from reallocation of emission rights, also tend to make the effects on welfare more disadvantageous.

We conclude that although the welfare effects of movements towards a more asymmetric allocation of emission rights are ambiguous, consumer surplus is very often adversely affected, and, therefore, firms' private incentive to trade typically exceed the social incentive.

3. Strategic Interaction

In the previous section, we have seen how the introduction of emission rights may create instruments for changes in industry structure with possibly adverse effects on economic welfare. In particular, when the number of emission rights to a given industry is fixed, there may be a tendency for monopolisation unless competition policy explicitly prevents it from happening. The underlying assumption, that the supply of emission rights to the particular industry in question is exogenously given, would be satisfied if all emissions originate in one industry and the number of permits issued by the authorities is fixed. Although examples exist where this could be the case (the UK electricity industry would come close, Newbery, 1990), usually a number of different industries will be in the market for any given type of pollution permits. Then a particular industry will face an elastic (residual) permit supply function (Hahn, 1984; Misiolek and Elder, 1988). Exit inducement and entry deterrence might still be possible in that case (see below) but are less likely. However there will still be scope for strategic behaviour via the emissions rights market. This section is devoted to a closer inspection of such issues by considering various extensions of the model presented in Section 2.

In the first two sub-sections I consider cases when either or both firms can commit themselves to holding quantities of pollution permits that differ from those that maximize short-run profits. Such commitments are credible only if the quantity of permits a firm possesses cannot be easily changed. This may be the case if a second-hand market for permits either does not exist or exchange involves transactions costs (see Footnote 4). However, even when the permits market functions perfectly, commitment can be achieved via long-run decisions on product design or the choice of production technology. The latter part of this section is thus devoted to an analysis of investment incentives in the presence of strategic interaction in permits and output markets.

3.1. THE EFFECT ON OWN COSTS

In this section I allow for elastic permit supply and extend the model to a two-stage game by introducing a pre-quantity-competition stage in which firms compete for emission rights. The main result is that strategic considerations give firms an extra incentive to invest in permits in order to reduce own marginal costs and become more aggressive in the output market.

Consider the following two-stage game. In Stage 1 emission rights can be bought in a market where the inverse supply function is given by $s(X + x)$, $s' > 0$, and X and x are the number of emission rights purchased by Firm 1 and 2, respectively. In the second stage the two firms play a Cournot quantity game. Let profits be given by

$$\Pi(Q, X; q, x) = r(Q; q) - c(Q, X) - s(X + x) \cdot X \tag{14}$$

$$\pi(q, x; Q, X) = r(q; Q) - c(q, x) - s(X + x) \cdot x \tag{15}$$

As in Section 2, we assume $c_{12} < 0$, i.e. more emission rights reduce marginal cost.

In the absence of any strategic considerations in the product market (e.g. because firms act as price takers in that market), firms maximize their profits by holding emission rights in quantities such that the first-order conditions $\Pi_X = 0$ and $\pi_x = 0$ are satisfied. I call these amounts of permits the 'cost minimizing levels of purchases', and they will be used as benchmarks for assessing the effects of strategic interaction in the market for outputs. However, as emphasized by Hahn (1984), these levels are generally not socially efficient if firms have market power in the market for emission rights. In particular, Hahn shows that firms which elect to buy (sell) permits will act similarly to a monopsonist (monopolist), i.e. purchase fewer (more) permits than is socially optimal. Whether or not firms elect to buy or sell will be determined by the initial allocation of emission rights. Since the analysis in this paper is concerned with how market power in the output market feeds back on behaviour in the market for emission rights, I abstract from the pure monopoly/monopsony effect by comparing actual levels of permits with firms' choices in the absence of strategic interaction in the product market. Note however, that in this model it is implicitly assumed that firms buy permits, and thus the first-order condition $\Pi_X = 0$ implies $-c_2 = s + s'X <$

s (and similarly for Firm 2). That is, ceteris paribus, the monopsony-power effect causes firms to underinvest in permits.

I look for the subgame perfect equilibrium of the game outlined above. In the second stage, Nash equilibrium conditions are given by (3) and (4). Consider then the Nash equilibrium in Stage 1 when firms simultaneously decide how many emission rights to buy taking into account effects on second-stage product-market competition. First-order conditions are:

$$0 = \frac{\mathrm{d}\Pi}{\mathrm{d}X} = \Pi_x + \Pi_q \cdot \frac{\mathrm{d}q}{\mathrm{d}X},$$

$$0 = \frac{\mathrm{d}\pi}{\mathrm{d}x} = \pi_x + \pi_Q \cdot \frac{\mathrm{d}Q}{\mathrm{d}x}, \tag{16—17}$$

where the fact that quantities are set optimally in Stage 2 has been used. Differentiating the first-order conditions for equilibrium in Stage 2 and solving, one gets:

$$\frac{\mathrm{d}Q}{\mathrm{d}x} = \frac{\Pi_{Qq}\pi_{qx}}{\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ}}, \text{ and}$$

$$\frac{\mathrm{d}q}{\mathrm{d}X} = \frac{\pi_{qQ}\Pi_{QX}}{\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ}}. \tag{18—19}$$

(Note that since the price of emission rights does not influence firms' marginal costs, $\partial\Pi_Q/\partial x = \partial\pi_q/\partial X = 0$.) From these expressions the following result is immediate.

PROPOSITION 5. If quantities are strategic substitutes, in particular, Π_{Qq}, $\pi_{qQ} < 0$, firms will overinvest in emission rights relative to the cost minimizing level of purchases ($\Pi_X = \pi_x = 0$, $i = 1, 2$).

The intuition for this result is the following. By increasing purchases of pollution permits a firm reduces its marginal costs. A negative shift in the marginal-cost curve induces the firm to increase its output thereby reducing the market price. Consequently the competitor, facing a lower market price (i.e. reduced residual demand), reduces his supply thus improving the performance of the first firm. This strategic effect therefore enhances the incentive to buy permits.

The result of proposition 5 echoes the familiar result in oligopoly theory that firms competing in strategic substitutes will overinvest in strategic variables that tend to make them more aggressive, i.e. the "Top Dog" strategy (see Tirole, 1988, chapter 8.3, and references cited therein). In this context the important point is that the introduction of emission rights creates a new variable which can be manipulated strategically in order to influence product market competition. It should be noted, however, that so far as welfare in the product market is concerned, the strategic effect tends to increase outputs and thus ameliorate the inefficiency due to imperfect competition.

Overinvestment in emission rights also raise rivals' fixed costs (as well as own costs) by increasing the permit price. Thus, even in the case when the supply of permits is not completely inelastic (as in the previous section), overinvestment in emission rights may be part of a preemptive/entry deterrence strategy.

Remark: If instead of strategic substitutes one considered strategic complements, in particular, a Bertrand price-competition model (assuming that prices are strategic complements) the above result would be reversed: Firms would underinvest in emission rights to keep up marginal costs and relax price competition (see Tirole op. cit.). For further comments on the Bertrand case, see below.

3.2. INFLUENCING RIVALS' MARGINAL COSTS

In the above model the strategic effect was due to the fact that the quantity of emission rights determine the position of the marginal production cost curve. In addition, if the right to pollute is paid for on an ongoing basis, rather than for a longer period of time, or if permits are continuously traded, strategic manipulation of the permit market may influence competitors' marginal costs directly through the permit price. The simplest way of demonstrating this is to consider a Stackelberg version of the game in the previous section: In the first stage only Firm 1 decides how many emission rights to purchase. In the second stage Firm 1's output decision and Firm 2's decisions about how much output to produce *and* how many emission rights to buy are taken simultaneously.

Taking into account optimal behaviour in Stage 2, the first-order condition for Stage 1 is

$$\Pi_X + \Pi_q \cdot \frac{\mathrm{d}q}{\mathrm{d}X} + \Pi_x \cdot \frac{\mathrm{d}x}{\mathrm{d}X} = 0. \tag{20}$$

From (20) we get the following result:

PROPOSITION 6. If quantities are strategic substitutes and marginal expenditure on emission rights by Firm 2 is increasing in the purchases of permits by Firm 1, i.e. $s''x + s' > 0$, then Firm 1 overinvests in emission rights relative to the cost minimizing level ($\Pi_X = 0$).

There are now two reasons why overinvestment is strategically optimal. First we have the Top Dog effect identified above: overinvestment shifts down the marginal-cost curve of Firm 1 and makes it more aggressive. However, there is an additional effect: by increasing its purchases in the permits market Firm 1 forces up the price of pollution permits. This leads to an increase in the marginal costs of Firm 2 and consequently a reduction in Firm 2's supply. This less aggressive action of Firm 2, i.e. a smaller output, benefits Firm 1. Note that, for overinvestment to occur, it is sufficient, but not necessary, that both conditions given in the proposition are satisfied. In particular, overinvestment may result even in the case of strategic complements or if Firm 1's marginal expenditure on permits is decreasing in X.

Remark: The Bertrand case provides an example in which the two effects work in opposite directions. Purchasing more emission rights raises the rival's marginal costs and makes him less aggressive, i.e. induces him to raise his price. On the other hand, more emission rights reduce own marginal costs (the capacity effect) and make a firm more aggressive, and consequently make the rival tougher. The overall effect is uncertain. It is interesting to note, however, that the prediction that firms will overinvest in emission rights can be true whether they compete in strategic substitutes or complements.

3.3. CHOICE OF TECHNOLOGY

We have seen how the emission-rights market may be manipulated by strategic agents in order to influence the behaviour of rivals. However, this may only be part of the story. Realizing the strategic potential of emission rights, firms will want to choose their technology to enhance the effectiveness of permits as strategic instruments. In this section we extend the model further to analyze this issue.[14]

We would like a model which captures the idea that the choice of technology is a long-run decision and at the same time incorporates the strategic effects identified in the two previous sections. The following two-stage game meets both these objectives while still being tractable: In the first stage Firm 1 can invest in abatement equipment to reduce/eliminate pollutants. In the second stage firms simultaneously decide how much to produce and how many emission rights to purchase.

Profits may now be written as

$$\Pi(Q, X, \theta; q, x) = r(Q; q) - c(Q, X, \theta) - s(X + x) \cdot X - k(\theta), \text{ and} \tag{21}$$

$$\pi(q, x; Q, X) = r(q; Q) - c(q, x) - s(X + x) \cdot x, \tag{22}$$

where θ is a technology parameter, and $k(\theta)$ is the cost of choosing θ, $k' > 0$.

We again look for a subgame perfect equilibrium. The first-order condition for Stage 1, taking into account optimal behaviour in Stage 2, is:

$$\Pi_\theta + \Pi_q \cdot \frac{\mathrm{d}q}{\mathrm{d}\theta} + \Pi_x \cdot \frac{\mathrm{d}x}{\mathrm{d}\theta} = 0. \tag{23}$$

We may then state the following result:

PROPOSITION 7. If quantities are strategic substitutes and more abatement equipment increases marginal cost of production, i.e. $\Pi_{Q\theta} \leqslant 0$, and reduces the marginal benefit of emission rights, i.e. $\Pi_{X\theta} \leqslant 0$, then Firm 1 will underinvest in abatement equipment relative to the cost minimizing level ($\Pi_\theta = 0$).

The intuition underlying the result of Proposition 7 is the following. First, reduced investment in abatement equipment shifts down the marginal cost curve of Firm 1. Second, it increases the marginal benefit of emission rights, which again leads to more aggressive behaviour in the permit market, i.e. more efficient use of the strategic benefits of emission rights.

Together $\Pi_{Qq} \leqslant 0$, $\pi_{qQ} \leqslant 0$, $\Pi_{Q\theta} \leqslant 0$, and $\Pi_{X\theta} \leqslant 0$ form a set of sufficient conditions for the underinvestment result. However none of these are necessary conditions by themselves. In particular, underinvestment may occur even if marginal production costs increase with higher levels of investment in abatement technology. Examples of such an inverse relationship between abatement investments and marginal costs are not uncommon. For example, a scrubber allows a coal-fired boiler to use low-cost high-sulphur coal.[15] To analyze this possibility I consider a simple example of the general model. Let Firm 1's profits be given by

$$\Pi = r(Q; q) - \tilde{c}(\theta) \cdot Q - s(X+x) \cdot X - k(\theta),$$
$$Q \leqslant X + \theta, Q, X, \theta \geqslant 0 \tag{24}$$

Marginal costs are constant and depend on the level of investment in abatement equipment. Furthermore, there is a fixed relationship between outputs of products and pollutants. Then, since θ and X have been normalized such that they can be measured on the same scale as Q, it follows that output cannot exceed gross pollution (emission plus cleaned waste). Profits of Firm 2 are similarly given by

$$\pi = r(q; Q) - s(X+x) \cdot x, 0 \leqslant q \leqslant x. \tag{25}$$

Assume that marginal costs take the particular iso-elastic form $\tilde{c}(\theta) = \theta^\gamma$ where γ is a (positive or negative) constant. Furthermore, let both the output-demand and the emission-right supply functions be linear, in particular,

$$P = 1 - bQ - cq$$
$$p = 1 - bq - cQ, b \geqslant c \geqslant 0,$$
$$s(X+x) = \alpha + \beta[X+x], \beta > 0, \tag{26—28}$$

I concentrate on the case in which the number of emission rights purchased is a binding constraint on the output of both firms, i.e. $Q = X + \theta$ and $q = x$ (a sufficient condition for this is $\alpha > 0$). First-order conditions for Stage 2 then reduce to:

$$\Pi_X = 1 - \alpha - \theta^{\gamma} - 2b\theta - 2[b+\beta]X - [c+\beta]x = 0, \text{ and}$$

$$\pi_x = 1 - \alpha - 2[b+\beta]x - [c+\beta]X = 0. \qquad (29\text{—}30)$$

Thus, the first-order condition for Stage 1 implies:

$$\Pi_\theta = \{[c+\beta]\cdot X + c\theta\} \cdot \frac{[c+\beta]\,[2b+\gamma\theta^{\gamma-1}]}{4[b+\beta]^2 - [c+\beta]^2}. \qquad (31)$$

From (26—28) it follows that the quantities of the two firms are strategic substitutes and that there is an inverse relationship between abatement investment and the marginal benefit of emission rights. Thus $\gamma \geqslant 0$ implies that the left hand side of (31) is positive and consequently Firm 1 underinvests in cleaning equipment relative to the cost minimizing level ($\Pi_\theta = 0$). The underinvestment result still holds if γ is negative but close to 0. In this particular example a negative sign of the left hand side of (31), and thus overinvestment in abatement equipment, is only compatible with γ being sufficiently negative.

4. Conclusion

We have seen that emission rights may create an instrument by which oligopolistic firms may try and influence their rivals' behaviour. It has also been shown that such strategic manipulation of the permit market may have anti-competitive, and moreover, negative welfare effects, in output markets.

It has been argued by some authors (Tietenberg, 1985, 1990) that strategic manipulation may not be a common problem in pollution control but arises only in special circumstances, notably in highly localized permit markets. However, when it exists, market power could potentially become a serious obstacle for efficient implementation of environmental standards through a program of tradable emission rights (Newbery, 1990; Hanley and Moffat, 1992). An alternative to emission rights which does not have such strategic consequences is emission charges. Emission charges have generally been criticised on the grounds that they require substantial information to implement given levels of emission, whereas tradable emission rights can achieve such goals in a much more direct way without the need for any information on demand and supply technologies in the regulated industries. The results of this paper provide additional support for the conclusion implicit in Hahn (1984) and Misiolek and Elder (1988), that this argument should be set against the possible anti-competitive effects of pollution permits.

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Appendix

In order to derive some of the comparative static results (Propositions 6—7), a number of auxiliary results on stability conditions in these types of models must first be established. In an unpublished note, which is available from the author upon request, I discuss stability conditions for Nash equilibrium in duopoly models where each duopolist has many decision variables, generalizing some of the results of Dixit (1986).

Proof of Proposition 1. Let $Q^*(X)$ and $q^*(X)$ be the equilibrium quantities of Firm 1 and 2 respectively when X emission permits are allocated to Firm 1. The proof then follows from the observation that for all $X \in [0, 1]$,

$$\begin{aligned}\Phi(1) &= \max_Q r(Q;0) - c(Q;1) \geqslant r(Q^*(X)+q^*(X);0)\\ &\quad - c(Q^*(X)+q^*(X);1) \geqslant r(Q^*(X);q^*(X)) - c(Q^*(X);X)\\ &\quad + r(q^*(X);Q^*(X)) - c(q^*(X);1-X) = \Phi(X). \qquad \text{(A.1)}\end{aligned}$$

QED.

Proof of Result 2. Let $c = 0$. Then each producer is in effect a monopolist. Since $\pi > 0$ only if $X < 1 - \rho$, industry profits are given by

$$\Phi(X) = \begin{cases} \dfrac{1}{4b}\left[1 - \dfrac{\rho}{X}\right]^2 + \dfrac{1}{4b}\left[1 - \dfrac{\rho}{1-X}\right]^2 & \text{if } 0.5 \leqslant X < 1-\rho \\ \dfrac{1}{4b}\left[1 - \dfrac{\rho}{X}\right]^2 & \text{if } 1-\rho \leqslant X \leqslant 1 \end{cases} \qquad \text{(A.2)}$$

It follows that for $X < 1 - \rho$,

$$\Phi'(X) = \frac{\rho}{2b}\left\{\rho\left[\frac{1}{[1-X]^3} - \frac{1}{X^3}\right] - \left[\frac{1}{[1-X]^2} - \frac{1}{X^2}\right]\right\}$$

$$\Phi''(X) = \frac{\rho}{2b}\left\{3\rho\left[\frac{1}{[1-X]^4} + \frac{1}{X^4}\right] - 2\left[\frac{1}{[1-X]^3} + \frac{1}{X^3}\right]\right\} \qquad \text{(A.3)}$$

$\Phi'(0.5) = 0$. Since $\Phi' > 0$ for $X > 1 - \rho$ and either (i) $\Phi'' > 0$ for all

$0.5 \leqslant X < 1-\rho$, or (ii) there exists $\bar{X} \in [0.5, 1-\rho]$ such that

$$\Phi''(X) \begin{cases} \leqslant 0 & \text{if } 0.5 \leqslant X \leqslant \bar{X} \\ \geqslant 0 & \text{if } \bar{X} \leqslant X \leqslant 1-\rho \end{cases} \tag{A.4}$$

$\Phi(X)$ can have at most one other extremum on $[0.5, 1-\rho]$, and if so, this is a (local) minimum. Therefore, to find the (global) maximum of $\Phi(X)$ it suffices to compare $\Phi(0.5)$ and $\Phi(1)$. Now, $\Phi(0.5) < \Phi(1)$ if $\rho < [\sqrt{2}-1]/[2\sqrt{2}-1]$. By continuity, the proposition follows. QED.

Proof of Result 3. The proof is similar to that of Result 2. Thus, for $X < 1-\rho$ one gets

$$\Phi'(X) = \frac{\rho[2b+\alpha]}{[3b+\alpha]^2}\left\{\rho\frac{b^2+[2b+\alpha]^2}{[b+\alpha]^2}\left[\frac{1}{[1-X]^3}-\frac{1}{X^3}\right]\right.$$
$$\left.-\left[\frac{1}{[1-X]^2}-\frac{1}{X^2}\right]-\rho\frac{2b[2b+\alpha]}{[b+\alpha]^2}\cdot\frac{2X-1}{X^2[1-X]^2}\right\}$$

$$\Phi''(X) = \frac{\rho[2b+\alpha]}{[3b+\alpha]^2}\left\{3\rho\frac{b^2+[2b+\alpha]^2}{[b+\alpha]^2}\left[\frac{1}{[1-X]^4}+\frac{1}{X^4}\right]\right.$$
$$\left.-2\left[\frac{1}{[1-X]^3}+\frac{1}{X^3}\right]-\rho\frac{2b[2b+\alpha]}{[b+\alpha]^2}\cdot\frac{5X^2+3X-1}{X^3[1-X]^3}\right\} \tag{A.5}$$

For α large enough these expressions may be approximated as follows:

$$\Phi'(X) \approx \frac{\rho[2b+\alpha]}{[3b+\alpha]^2}\left\{\rho\left[\frac{1}{[1-X]^3}-\frac{1}{X^3}\right]-\left[\frac{1}{[1-X]^2}-\frac{1}{X^2}\right]\right\}$$

$$\Phi''(X) \approx \frac{\rho[2b+\alpha]}{[3b+\alpha]^2}\left\{3\rho\left[\frac{1}{[1-X]^4}+\frac{1}{X^4}\right]-2\left[\frac{1}{[1-X]^3}+\frac{1}{X^3}\right]\right\} \tag{A.6}$$

Then by a similar reasoning as in the proof of Result 2, given the condition on ρ it suffices to compare

$$\Phi(0.5) = \frac{2b+\alpha}{[3b+\alpha]^2}[1-2\rho]^2, \text{ and}$$

$$\Phi(1) = \frac{1}{2[2b+\alpha]}[1-\rho]^2. \tag{A.7}$$

Since for α large enough, $\Phi(0.5) > \Phi(1)$, the proposition follows. QED.

Proof of Result 4. Using a similar argument to that in the proofs of Propositions 2 and 3, it suffices to compare welfare at $X = 0.5$ and $X = 1$, given by

$$W(0.5) = \frac{3}{8b}\,[1 - \rho]^2,$$

$$W(1) = \frac{4}{9b}\,[1 - 2\rho]^2. \tag{A.8}$$

Straightforward calculations give the result. QED.

Proof of Proposition 5. Rewriting (16—17) and using the second-order conditions for Stage 2, we have

$$\Pi_X = -\Pi_q \cdot \frac{\mathrm{d}q}{\mathrm{d}X} < 0, \tag{A.9}$$

and similarly, $\pi_x < 0$. Since Π_{XX}, $\pi_{xx} < 0$ around the cost minimizing levels of purchases ($\Pi_X = \pi_x = 0$), $k = 1, 2$, it follows that X and x exceed these levels. QED.

Proof of Proposition 6. First-order and second-order conditions for equilibrium in Stage 2 are:

$$\Pi_Q = 0, \tag{A.10}$$

$$\pi_q = 0,\ \pi_x = 0, \tag{A.11}$$

$$\Pi_{QQ} < 0, \tag{A.12}$$

$$\pi_{qq} < 0,\ \pi_{xx} < 0, \text{ and } \pi_{qq}\pi_{xx} - [\pi_{qx}]^2 > 0. \tag{A.13}$$

From the first-order conditions for Stage 2 we get:

$$\frac{\mathrm{d}q}{\mathrm{d}X} = \{\Pi_{QQ}\pi_{qx}\pi_{xX} + \Pi_{QX}\pi_{qQ}\pi_{xx}\} \cdot |A_3|^{-1},$$

$$\frac{\mathrm{d}x}{\mathrm{d}X} = -\{[\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ}] \cdot \pi_{xX} + \Pi_{QX}\pi_{qQ}\pi_{qx}\} \cdot |A_3|^{-1}, \tag{A.14}$$

where

$$|A_3| = \begin{vmatrix} \Pi_{QQ} & \Pi_{Qq} & 0 \\ \pi_{qQ} & \pi_{qq} & \pi_{qx} \\ 0 & \pi_{xq} & \pi_{xx} \end{vmatrix} \tag{A.15}$$

The conditions for stability of the equilibrium (see von der Fehr, 1992) imply $|A_3| < 0$ and $\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ} > 0$. The assumption that $s''x + s' > 0$ (a sufficient condition for this is that s($\cdot$) is convex) implies

$$\pi_{xX} = -[s''x + s'] < 0, \tag{A.16}$$

From this, and the conditions that quantities are strategic substitutes and emission rights reduce marginal costs, we have

$$\frac{\mathrm{d}q}{\mathrm{d}X} < 0, \text{ and } \frac{\mathrm{d}x}{\mathrm{d}X} < 0. \tag{A.17}$$

It follows that $\Pi_X < 0$ in equilibrium and thus that Firm 1 overinvests in emission rights relative to the cost minimizing solution. QED.

Proof of Proposition 7. First-order conditions for Nash equilibrium in Stage 2 are:

$$\Pi_Q = 0, \Pi_X = 0, \text{and} \tag{A.18}$$

$$\pi_q = 0, \pi_x = 0. \tag{A.19}$$

The corresponding second-order conditions are:

$$\Pi_{QQ} < 0, \Pi_{XX} < 0, \Pi_{QQ}\Pi_{XX} - [\Pi_{QX}]^2 > 0, \tag{A.20}$$

$$\pi_{qq} < 0, \pi_{xx} < 0, \text{and } \pi_{qq}\pi_{xx} - [\pi_{qx}]^2 > 0. \tag{A.21}$$

From the first-order conditions for Stage 2:

$$\begin{aligned}\frac{\mathrm{d}q}{\mathrm{d}\theta} &= \{-\Pi_{X\theta}[\Pi_{QQ}\pi_{qx}\pi_{xX} + \Pi_{QX}\pi_{qQ}\pi_{xx}] \\ &\quad + \Pi_{Q\theta}[\Pi_{XQ}\pi_{qx}\pi_{xX} + (\Pi_{XX}\pi_{xx} - \Pi_{Xx}\pi_{xX})\pi_{qQ}]\} \cdot |A_4|^{-1}, \\ \frac{\mathrm{d}x}{\mathrm{d}\theta} &= \{\Pi_{X\theta}[(\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ})\pi_{xX} + \Pi_{QX}\pi_{qQ}\pi_{qx}] \\ &\quad - \Pi_{Q\theta}[\Pi_{XQ}\pi_{qq}\pi_{xX} + \Pi_{XX}\pi_{qQ}\pi_{qx}]\} \cdot |A_4|^{-1},\end{aligned} \tag{A.22—23}$$

where

$$|A_4| = \begin{vmatrix} \Pi_{QQ} & \Pi_{QX} & \Pi_{Qq} & 0 \\ \Pi_{XQ} & \Pi_{XX} & 0 & \Pi_{Xx} \\ \pi_{qQ} & 0 & \pi_{qq} & \pi_{qx} \\ 0 & \pi_{xX} & \pi_{xq} & \pi_{xx} \end{vmatrix}. \tag{A.24}$$

The stability conditions (see von der Fehr, 1992) imply $|A_4| > 0$, $\Pi_{QQ}\pi_{qq} - \Pi_{Qq}\pi_{qQ} > 0$, and $\Pi_{XX}\pi_{xx} - \Pi_{Xx}\pi_{xX} > 0$. This and the assumptions of strategic substitutability of output, and that emission rights reduce marginal costs, $\Pi_{Q\theta} < 0$, and $\Pi_{X\theta} < 0$, then give

$$\frac{\mathrm{d}q}{\mathrm{d}\theta} > 0, \text{ and } \frac{\mathrm{d}x}{\mathrm{d}\theta} > 0. \tag{A.25—26}$$

It follows from (23) that in equilibrium, $\Pi_\theta > 0$, and thus that Firm 1 underinvests in abatement equipment relative to the cost minimizing level. QED.

Notes

[1] Authors vary in what they prefer to call such instruments. In this paper the terms "emission rights", "emission licenses", and "pollution permits" will be used interchangeably.
[2] If the efforts to reduce sulphur dioxide emissions in the U.K. become part of e.g. an EEC wide program, the market power issue would most likely disappear in so far as the electricity industry is concerned.
[3] Tietenberg (1985) points out that strategic manipulation might have become a problem in the Piceance Basin in Colorado where permit users all intended to extract shale oil. In practice the problem never materialized because the market for shale oil tumbled and those companies never actually commenced operation. In a completely different setting, it has been suggested to introduce tradable fishing rights on the Norwegian coast line. One of the arguments raised against the proposal is that it would lead to concentration and exclusion, in particular of the small scale fishing boats of the northern regions of Norway.
[4] It is interesting to note that under permit trading schemes, e.g. under the EPA's Bubble Policy or the Fox River scheme, both in the U.S., few trades have been made, and even fewer have been between different firms. This may be because of transactions costs or because firms believe that by hoarding they increase their allocation of permits in the next round. However, an alternative explanation, at least for members of the same industry, is that firms do not want to sell to a buyer who is in product-market competition with them (see Hahn, 1989, for a discussion).
[5] With the U.K. electricity industry example in mind, throughout this paper I concentrate on the duopoly case. However the analysis extends straightforwardly to oligopoly models although presumably strategic effects would be weaker the greater the number of firms in the market. Bertrand price competition, as an alternative hypothesis of conduct, is briefly discussed in Section 3.
[6] A similar type of analysis is undertaken by Joseph Farrell and Carl Shapiro (1990a, b) who consider the effects of changes in ownership of productive assets in a homogeneous-goods Cournot oligopoly model, in particular, the sale of capital goods by one oligopolist to another. In a completely different setting, Pankaj Ghemawat (1990) demonstrates how the evolution of industry structure may involve increasing asymmetries and dominant positions due to the monopolization of new investment opportunities by the larger competitor. Also, in this model, which involves price competition both in input and output markets, the driving force is that industry profits increase with the share of aggregate productive assets accounted for by the larger firm.
[7] For analytical convenience, it will be assumed throughout that emissions, and thus emission rights, are homogeneous "goods", i.e. are not differentiated according to the geographical origin of emissions or the identity of the polluter (Montgomery, 1972; Tietenberg, 1990). The results seem to generalize straightforwardly to a more general setting.
[8] $\Pi_Q \equiv \partial\Pi/\partial Q$, $\Pi_X \equiv \partial\Pi/\partial X$, $\Pi_q \equiv \partial\Pi/\partial q$, $\Pi_{QQ} \equiv \partial^2\Pi/[\partial Q]^2$, $\Pi_{QX} \equiv \partial^2\Pi/\partial Q\partial X$, etcetera (and similarly for Firm 2). r_i and c_i denote partial derivatives with respect to the i'th variable, while r_{ij} and c_{ij} denote the cross derivatives with respect to the i'th and j'th variables, $i, j = 1, 2$.
[9] Note that even though size is defined in terms of the number of emission rights held, output is typically increasing in the number of permits and so Firm 1 will be the larger firm as measured by output also.

[10] For expositional convenience, the asterisk indicating equilibrium values, is generally dropped.
[11] See the argument in the proof of proposition 4, p. 283, in Farrell and Shapiro (1990a).
[12] Tirole (1988) pp. 207—208 provides a discussion of the terms 'strategic substitutes' and 'strategic complements', originally coined by Bulow *et al.* (1985).
[13] All proofs have been relegated to an appendix.
[14] The more general question of how emission rights may affect firms technology decisions over time, in particular, their incentives for R&D and innovation, will not be considered here. See Magat (1978) for an analysis of how the allocation of a firm's investment in resources to improve it's abatement and production technologies is influenced by environmental policies. More specifically, see Downing and White (1986) and Malueg (1989) on how markets for emission rights affects a firm's decision to adopt more effective pollution-control technologies.
[15] I am grateful to one of the referees for suggesting this example.

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