Tradeable Emission Permits in Oligopoly

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by

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Abstract

The paper considers an oligopolistic industry in which pollution is a by-product of production. Firms are assumed to have emission permits that restrict the amount that they pollute. These permits are assumed to be tradeable and the paper discusses a structure in which the same set of firms operates both in the product market as well as in the pollution permits market. The paper demonstrates that in such a structure allowing trade in emission permits is not necessarily beneficial. In particular it may lead to the choice of inferior production and abatement technologies, it may lead to a market equilibrium with lower output rates and higher prices and it may result in a shift of production from a low cost to a high cost firm.

Introduction

Imposing an emission standard is an effective instrument that guarantees a reduction of pollution. The advantages of such an instrument, versus emission taxation, has been extensively discussed by Baumol and Oates (1988)[1]. The main difficulty facing policy makers, beyond determining the optimal levels of emission permits, is to find an efficient mechanism of allocating the permits. The problem resembles any problem of allocating administrative quotas. Since firms may differ in their production costs and abatement costs as well as in their emission/ output ratios, an efficient allocation of permits must take all this information into account. However, such information is usually not available for policy makers.

One of the mechanisms, commonly suggested by practitioners as well as academics, is not just to impose a pollution standard but also to provide a market for pollution rights as is already done in the USA (e.g. Foster and Hahn (1995)). In such a market an emission standard is split into a number of permits which can be traded among firms. Tradeable emission permits, as an instrument for environmental policy, was first introduced by Dales (1968). The idea behind such a mechanism is that firms that produce more efficiently may buy permits from less efficient firms and thus may be able to produce a larger share of the output. Such a switch clearly promotes overall productive efficiency as the more efficient firm produces a larger share of the total output.

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[1] Emission permits realize the standard right away whereas taxation requires a process of learning before the target is reached. In inflationary markets, for example, policy makers have to adjust the emission taxes whereas permits need not be adjusted. Policy makers also have more flexibility in controlling the extra costs for the firms.

The implication of tradeable emission permits, however, may crucially depend on the industry market structure. The argument for efficiency is intuitive in perfectly competitive markets which has been the main focus of the research so far. In such markets the price that clears the market for emission permits equalizes the marginal abatement costs (e.g. Montgomery, 1972). This argument, however, cannot be extended to oligopolistic markets. Moreover, one should distinguish between the market structure of the product market and that of the market for emission permits. As an example one may consider the SO_2 pollution in the UK. Owen et. al. (1992) analyzed the possible market mechanisms to control this type of pollution. According to their analysis, which is based on the 1989 situation, the electricity industry accounts for 71 % of all SO_2 emissions and this industry is dominated by two firms: National Power and PowerGen. Both firms have emission permits but these permits were not tradeable. In discussing the introduction of markets for permits the report refers to the American experience. However, this experience is not necessarily relevant as the US market for permits is relatively competitive while the U.K. market for permits would be more concentrated. Our analysis, of an oligopolistic emission permit market, is more relevant for the European markets than for the American market.

The focus of this paper is on the effect of tradeable permits on the equilibrium in an oligopolistic market in which the firms that compete in the product market are the same firms that trade the emission permits. The permits market, in such a case, has a very special structure in which there are both a few buyers and a few sellers. We therefore assume that the number of permits that are traded and the terms of the trade are determined by a bargaining process between the firms. The bargaining involves only the cash sale of permits without allowing to condition the permits transfer on output in the product market. Thus collusion via the permits market is prohibited but clearly firms will use the permits market to arrive at a favorable equilibrium in the product market. In particular, permits may serve as a precommitment device through which the industry may manipulate the product market equilibrium.

Since firms negotiate the terms of trade of permits and they are free to determine the money transfer, they may easily implement asymmetric equilibria that may enhance their joint profits. The firm that gets the small share at this equilibrium can be compensated earlier at the permits trade stage. The paper considers several cases with different levels of the emission standard. We show that in some cases the possibility to trade permits causes a reduction of industry output and even a production shift from a low to a high cost firm. In such a case production cost may increase but the shift of permits to the high cost firm enables the firms to commit to lower output levels and thus to a higher price. In such cases we show that merely the possibility to trade permits causes further reduction in pollution beyond the level that is imposed by the combined emission permits. The paper demonstrates that changing pollution permits is sometimes not an effective policy instrument. That is, we identify cases in which small changes of permits do not affect overall pollution. The paper also considers the firms' choice of abatement technology and shows that merely the possibility to trade emission permits may lead the firms to choose inferior technologies.

In a recent paper Malueg (1990) analyses an oligopolistic goods market in combination with a perfectly competitive permits market. Trading emission permits is here characterized as lowering marginal costs of production. He shows that uneven cost reductions may shift production from low cost to high cost firms which may be detrimental for industry profits and therefore for welfare, even though total output and thus consumers' surplus will rise. Von der Fehr (1993) analyses a two-stage game where two firms first buy permits in an imperfectly competitive permits market and then play a Cournot game on the goods market. As in similar type of models, strategic overinvestment in permits results. The paper mentions the possibility of monopolization through trade in permits but does not elaborate much on this issue. Requate (1992) analyses this monopolization on the basis of a two-stage model but these papers are not considering the possibility of abatement. Sartzetakis (1995) considers the same situation as Malueg (1990) but models emission ceilings and abatement costs explicitly. Although the permits market is assumed to be perfectly competitive, it is also assumed that one duopolist demands permits and the other one supplies permits which determines the equilibrium price. In this construct it is shown that the market share of the firm that is more efficient in abatement decreases, although under reasonable assumptions welfare still increases. We differ from this paper by considering a market in which the same set of firms plays in both markets emphasizing the strategic interaction between the two markets.

1. The Model

Consider a duopolistic market in which both firms produce an homogeneous good. The demand function is assumed to be linear such that $p = p^0 - (q_1 + q_2)$ where q_i is the output of firm i and p is the market price. Production cost is assumed to be linear such that c_i is the constant marginal cost of firm i.

We assume that pollution is a by-product of production such that the amount of pollution associated with producing the output level q_i is $\alpha_i q_i$. We assume that firms have different coefficient of pollution, α_i, but that $\alpha_i < 2\alpha_j$. Furthermore, firms also have the possibility of abatement. We denote the level of abatement by firm i as a_i, and the cost of abatement is assumed to be linear and given by

$\gamma_i a_i$. The overall pollution by firm i, denoted hereafter as d_i, is therefore

$$d_i = \alpha_i q_i - a_i \ . \qquad \textbf{(1)}$$

In order to reduce pollution, the government adopts a policy of an emission standard e and a division of this standard between the two firms. Specifically, each firm is given a permit of $e_i \geq 0$ which prescribes the upper limit of pollution that firm i is allowed to make with $e_1 + e_2 = e$. Firms that wish to produce beyond the level of e_i/α_i must therefore abate.

Consider now a mechanism that firms are allowed to transfer or to sell all, or part, of their emission permits, i.e. to sell their "rights to pollute". We restrict, however, the set of possible contracts between the firms to allow only for cash contracts. That is, a firm may buy or sell its emission rights only for cash. In particular, contracts are not allowed to depend on the quantities produced or sold by the firms, or on the market price. Clearly allowing firms to contract on quantities may facilitate collusion in the product market and, therefore, will be objected by the antitrust authorities.

We thus consider the following problem. Suppose firms have the emission permits e_1 and e_2 respectively and they negotiate a transfer of emission permits. The transfer to firm i is denoted by t_i and since there are only two firms $t_i = -t_j$ for $j \neq i$. The transfer of emission permits is accompanied by a cash transfer T_i from firm i to firm j, $T_i = -T_j$. The mechanism of trade that determines the number of permits to be transferred and the accompanying cash payment is a bargaining between the two firms. For simplicity we assume the Nash bargaining solution. The final permit that each firm has is denoted by k_i and is given by $k_i = e_i + t_i$. Given (k_i, k_j), the firms are engaged in a Cournot type duopolistic competition in which each firm determines its output and abatement levels.

We consider the subgame perfect equilibrium of the game described above. We first analyze the duopoly given arbitrary emission permits k_i. We then analyze the terms of the pollution permits trade.

1.1 The Duopolistic Game

Consider a Cournot type duopolistic game in which the firms have the emission permits (k_i, k_j). Firm i's objective function is

$$\begin{aligned} &Max_{q_i}\,(p^0 - (q_1 + q_2))q_i - c_i q_i - \gamma_i a_i \\ &s.t. \\ &\alpha_i q_i - a_i \le k_i\,. \end{aligned} \qquad \textbf{(2)}$$

As long as $\alpha_i q_i \le k_i$ firm i behaves as a regular profits maximizing firm without the need to abate. The abatement cost affects the firms's behavior only when its output pollutes beyond its emission permit. In such a case firm i must abate the surplus of $\alpha_i q_i - k_i$. In such a range of output rates the firm's maximization problem is

$$Max_{q_i}\,(p^0 - (q_1 + q_2))q_i - c_i q_i - \gamma_i(\alpha_i q_i - k_i) \quad . \qquad \textbf{(3)}$$

The above maximization problem yields the following reaction function[2]:

$$\begin{aligned} &q_i = (p^0 - q_j - c_i)/2 \qquad\qquad if \quad \alpha_i q_i \le k_i \\ &q_i = (p^0 - q_j - c_i - \gamma_i \alpha_i)/2 \qquad if \quad \alpha_i q_i > k_i \quad . \end{aligned} \qquad \textbf{(4)}$$

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[2]This duopolistic interaction is similar to the interaction between firms in which each firm has a capacity constraint but the capacity may be increased at some cost (see for example Eaton and Lipsey (1981) and Dixit (1980)).

Figure 1 about here

The reaction functions of the two firms are depicted in Figure 1. Given an emission permit for firm 1, k_1, its reaction function is on the upper part of line M_1M_1' as long as $q_1 < k_1/\alpha_1$. At this output level the reaction function jumps to the lower line as for every larger output level the firm needs to take into account its abatement cost.

Note that any point in the area ABCD may be an equilibrium of the duopolistic interaction depending on k_1 and k_2. If k_1 and k_2 are sufficiently large, the equilibrium will be at C which is the Cournot equilibrium point when pollution is ignored. When the emissions permits are very low the equilibrium is at point A which also implies lower quantities and a higher price. In order to assure that in all the above cases both firms produce in equilibrium, we further assume that $\gamma_i\alpha_i < ½(p^0+c_j-2c_i)$ for i,j=1,2 and $i\neq j$.

For every (k_1,k_2) there is a unique equilibrium in the duopolistic game. We denote the duopolistic equilibrium payoffs of firm i as $\pi_i^N(k_i,k_j)$. These payoffs include cost of production and abatement but exclude the revenues of the sale of emission permits.

It would be useful to observe that when the equilibrium is on the lines CB, CD or in the interior of the area ABCD then no abatement occurs in equilibrium and both firms pollute either at or below their emission permits. When the equilibrium is at a point on the line AB or AD at most one firm abate. When the equilibrium is on the line AB firm 1 does not abate and when it is on the line AD firm 2 does not abate. Only in point A it is possible that both firms abate in equilibrium (unless at least one of the permits is exactly equal to $\alpha_i A_i$).

1.2. Transfer of Emission Permits

Having in mind the effect of emission permits on the product market equilibrium the firms are engaging in a bargaining game trying to determine which firm will sell permits and what will be the cash compensation for this exchange. If firms do not trade their emission permits their final payoffs would be ($\pi_1^N(e_1,e_2)$, $\pi_2^N(e_1,e_2)$). Therefore in discussing the bargaining game between the firms these profits may be viewed as their outside alternatives or the threat point. We adopt the Nash bargaining solution as our solution concept for the bargaining game. We are thus looking for k_1 , k_2 , T_1 , T_2 that maximize the following expression.[3]

$$_{,T_1,T_2}\left(\pi_1^N(k_1,k_2) - \pi_1^N(e_1,e_2) + T_1\right)\left(\pi_2^N(k_1,k_2) - \pi_2^N(e_1,e\right. \qquad \textbf{(5)}$$

$$T_1 = -T_2$$

$$k_1 + k_2 = e_1 + e_2 \quad .$$

The ability to transfer cash between the firms simplifies the above bargaining game considerably. The side payments and the assumption of linear preferences implies that the bargaining set is linear. In such a case the Nash bargaining solution indicates that the surplus will be equally divided between the players. Thus the solution of the above bargaining game is a simple procedure of finding the allocation of permits (k_1, k_2), with $k_1+k_2 = e$, which maximizes the firms' joint profits and then identify the transfer T_i that equally divides the benefit of the permits transfer.

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[3] Note that since we allow for side payments the bargaining set is convex.

2. The Equilibrium Trade of Permits

The initial permits define a line along which the firms may trade. That is, in every trade the constraint is that the resulting total emission permit, $k_1 + k_2$, must be equal to the overall standard e. The firms can neither create permits nor give up on permits. The trade in permits may affect several aspects of the market interaction. It may change the total equilibrium output and thus affect price, revenues and therefore allocative efficiency. The permits trade may also affect market shares and consequently productive efficiency. Finally, it may affect total abatement cost and overall pollution as the equilibrium pollution may be less than the permits allow for.

Our analysis will be according to the following procedure. For every initial emission permits (e_1,e_2) we will find the set of possible product market equilibria that can be achieved by trading emission permits at the second stage and then playing a Cournot type game on the product market. Once the feasible set is recognized by the firms, they will choose the emission combination that maximizes their joint profits. Since side payments, in the form of transfer payments for permits, are allowed in this procedure, firms will arrange the transfer so that the gain from the permit trade will be evenly divided between them. Note that the even split results from our assumption that both firms are risk neutral.

It is useful to distinguish among several cases depending on the total initial emission standard, i.e. the location of the line $\alpha_1 q_1 + \alpha_2 q_2 = e$ with respect to the feasible equilibria set ABCD. To illustrate the different forces we first consider the two extreme cases. In the first one the emission standard is very low. This is our benchmark case as it covers the basic intuition and rationale for permits trade, namely that firms use this trade to economize on abatement cost. In the second extreme case the emission standard is so high that each firm has enough permits to produce the regular Cournot equilibrium output without the need to abate.

Case 1 (Low emission permits): $e/\alpha_i < A_i$ for i=1,2.

When $e/\alpha_i < A_i$ for i=1,2, the permits are so low that firms cannot use trade in emission permits to change the equilibrium output levels.

Proposition 1: When both firms get low emission permits such that $e/\alpha_i < A_i$ for i=1,2, the firm with the lower cost of abatement, firm i, sells *all* its pollution permits to its competitor. The cash transfer is $T_i = e_i(\gamma_j + \gamma_i)/2$. The permit transfer does not change, in such a case, the market output and the price but firms economize on abatement cost.

Proof: Since $e/\alpha_i < A_i$ for i=1,2, any trade in emission rights will not change the equilibrium point in the product market game that remains to be point A. The firms, however, may benefit from the trade by economizing on abatement cost. The best thing to do is to shift all emission rights to the firm that is less efficient in abatement and to let the more efficient firm do all the abatement. The saving in abatement costs resulting from such a shift is $e_i(\gamma_j - \gamma_i)$, which by the Nash bargaining solution is divided equally between the firms. ■

The case of low emission permits illustrates the standard argument for allowing trade in permits. Firms with high abatement cost buy the permits from the low abatement cost firms and make the abatement process more efficient. This case was simple because there was no interdependence between the permit market and the product market.

Case 2 (High emission permits): $e_i/\alpha_i > C_i$ for i=1,2.

Assume now that both firms are given high emission permits such that $e_i/\alpha_i > C_i$, i=1,2, where C_i is the quantity firm i produces at the Cournot equilibrium when pollution is ignored. The imposition of such emission permits itself does neither affect the market equilibrium nor the overall pollution. If trade is not allowed, the market equilibrium continues to be at point C.

Figure 2 about here

Assume now that the emission permits are tradeable. Because the high permits are in fact non-binding constraints with respect to pollution, firms are not abating and therefore saving on abatement cost cannot be a reason for trade in permits. Thus, the only reason firms may have for trading is the possible beneficial effect of trading on the product market equilibrium, i.e. quantities and price.

Proposition 2: When both firms get high emission permits such that $e_i/\alpha_i > C_i$ for i=1,2,

(i) the possibility to trade emission will *always* cause a reduction of the overall output and a higher price

(ii) the possibility to trade emissions *reduces* the equilibrium pollution level even *below* the level implied by the permits, i.e. below $e_1+e_2 = e$.

Proof: Once firms are given the permits e_i they can trade the permits along the line $\alpha_1 q_1 + \alpha_2 q_2 = e$. This line passes above the feasible equilibria area ABCD (see Figure 2)[4]. By choosing points along this line the firms can in fact determine the equilibrium of the market game. One can easily observe that given the location of the trading line $\alpha_1 q_1+\alpha_2 q_2 = e$ the firms can choose every point on the lines BC and DC as their equilibrium point by making the appropriate trade in permits.

Note that any point on [D,C) or [B,C) implies lower overall output and a higher price than at point C. Similarly note that any such point represents a lower overall pollution level than e. It remains to be shown that indeed firms would prefer to use the trading mechanism to move from point C to one of the other feasible equilibrium points.

In case $c_2 \geq c_1$, a small move from point C towards point B raises total profits. First note that any such shift implies lower overall output. Since at the Cournot equilibrium firms produce beyond the monopoly level that maximizes total profits such a reduction increases the combined profits. Moreover moving along CB implies that production shifts from the firm with the higher production costs to the firm with the lower production cost. Therefore firms will always trade permits to move away from point C. ■

Note that while proposition 2 considers only the case with $e_i/\alpha_i > C_i$ for i=1,2, any case in which the firms have permits along the same trading line will yield the same results. Given a level of the combined permits, e, firms choose from the output combinations, that can be implemented as equilibrium output, the one that maximizes total profits. Since the allocation of e between the firms

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[4] Here we use our assumption that $\alpha_i < 2\alpha_j$; without such an assumption the feasible line $\alpha_1 q_1+\alpha_2 q_2 = e$ may cross the feasible diamond ABCD.

does not change the feasible set, firms will choose the same point regardless of the initial division of e between them.

Corollary: The above analysis indicates that when the imposition of restrictive pollution permits is politically difficult, one can achieve a reduction in pollution by imposing non-restrictive permits and then allowing firms to trade those permits. Such a combination of policy tools might be more acceptable than standard restrictive permits.

So far we have showed that firms will not stay at the Cournot equilibrium point C as moving towards point B is always profitable. Moreover, one can easily observe that along the [C,B] segment, joint profits are maximized at point B as firms would like to choose a point as close as possible to the monopolistic point M in which all production is done by the low cost firm. Firms, however, also have the option of implementing an equilibrium point on the [C,D] line segment. In such a case there are two conflicting effects. On the one hand restricting output will increase joint profits while on the other hand production is shifted from the low cost to the high cost firm, increasing overall costs of production. Given the possibility of such a productive inefficiency it is important to examine the circumstances under which the firms, as a result of trade in pollution permits, would choose to shift output from the low cost to the high cost firm.

Because the slopes of the two reaction functions are inversely proportional a small shift towards point B yields the same output reduction as an identical shift towards point D. On the other hand if $c_1 < c_2$ moving towards B will lower overall production cost. Thus, a shift towards B is superior to any identical shift towards D. However, it is possible that the firms by moving towards

D can credibly restrict their output even further than by moving in the other direction. In such a case they will choose to move towards D.

Let β be the point on the CM_2 line that represents the same industry output (and revenues) as point B. If β falls to the left of D (and therefore cannot be reached at equilibrium) the firms will choose point B as it yields the highest feasible profits. If β falls to the right of D the firms have a dilemma. By letting the high cost firm have more of the permits the firms can commit to lower total output than at point B but at the expense of higher production cost. Specifically,

Proposition 3: Allowing permits trade may lead to production inefficiency as it may cause an output shift from the low cost to the high cost firm. Such a shift occurs if one of the following situations occurs:

(i) $0 < a \leq 2\gamma_1\alpha_1$ and $2\gamma_2\alpha_2 < b - (b^2-a^2)^{½}$

(ii) $2\gamma_1\alpha_1 \leq a$ and $2\gamma_2\alpha_2 < b - (b^2- 4\gamma_1\alpha_1(a - \gamma_1\alpha_1))^{½}$,

where $a = p^0 + 4c_1 - 5c_2$ and $b = p^0 - 5c_1 + 4c_2$.

Proof: See Appendix. ■

One can interpret the conditions in proposition 3 in the following way. In order for the firms to decide to move from C towards D it first must be that β is to the right of D so that the firms are able to restrict output even below the level at B (which is implied by $\gamma_2\alpha_2 < \gamma_1\alpha_1$). Secondly, it must be that such a move is more profitable than moving to the other direction, i.e. that the benefits of a further restriction of output outweigh the difference in production cost. As we discussed before the profits from moving towards B depend on how much the firms can move to this direction and this is governed by $\gamma_2\alpha_2$. The conditions in the proposition require an upper limit on $\gamma_2 \alpha_2$. Subcase (i) refers to the situation where the point with maximal joint profits lies inside the CD segment so that the upper limit on $\gamma_2\alpha_2$ does not depend on how much further output could be restricted by moving towards D. However, in subcase (ii) the point with maximal joint profits falls to the left of D so that the upper limit on $\gamma_2\alpha_2$ depends on $\gamma_1\alpha_1$, which governs the position of D.

The two extreme cases show the main mechanisms that are at work. Combining these mechanisms leads to a myriad of possible outcomes. We will now briefly consider these intermediate cases.

Case 3 (Intermediate level permits): $e/\alpha_i > A_i$ for i=1, 2 or both, and $\alpha_1 C_1 + \alpha_2 C_2 > e$.

There are several types of intermediate cases that one can consider. We describe these cases in Figure 3a-3d. Note that in all these cases the emission permits present binding constraints as the Cournot equilibrium cannot be implemented. We will only outline the analysis of these cases pointing out the different possible effects of allowing permits' trade.

Figure 3 about here

Case 3a: $\alpha_1 B_1 + \alpha_2 B_2 < e$, $\alpha_1 D_1 + \alpha_2 D_2 < e$ and, $\alpha_1 C_1 + \alpha_2 C_2 > e$.

In case 3a the permits are sufficiently low so that the Cournot equilibrium point C cannot be implemented. One can easily check that in such a case the equilibrium points that the firms can implement are on B'B, D'D and on the interior line D'B' (see Figure 3a). Note that in all these points there is no abatement. The firms will trade permits to support the point in this set that yields the highest joint profits.

The type of equilibrium we will get in this case depends on the position of β with respect to D' and D. If β is on the left of D then like in the previous case the firms will choose to be in point B. If β is between D and D' then like in the previous case the firms will choose point B or a point on βD. If, however, β is on the right of D' then the firms may also choose an interior point on D'B' with a lower output than at point B. Note that, like in proposition 2, when β is on the left of D' the permits constraint will not be binding as firms will choose an equilibrium point with a pollution level below the permits. When β is on the right of D', the possibility to be on the D'B' line implies that the firms might choose an equilibrium that yields overall pollution identical to the standard. This distinction is important because of its implication on the effectiveness of a policy that further lowers the standard.

<u>Corollary</u>: In case 3a the overall pollution level might be insensitive to small changes in the pollution permits. When β is on the left of D' a relatively small change in the permits does neither affect the market equilibrium nor the level of pollution. Hence, in such a case a policy that lowers the standard will not be effective in lowering overall pollution[5].

Note, however, that in the symmetric case when the firms are identical they will choose either point B or point D. In such a case one can observe that the overall equilibrium pollution is less than

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[5] Such an effect might also hold when β is on the right of D' but when the firms choose an interior point on the D'B' line small changes in permits will be effective.

what the permits allow for and a small reduction in the overall standard will not affect the industry's pollution.[6]

Case 3b: $A_1 < e/\alpha_1 < B_1$, $A_2 < e/\alpha_2 < D_2$, and $\alpha_1 A_1 + \alpha_2 A_2 > e$.

In case 3b the overall standard is somewhat higher than in case 1 but it is sufficiently low so that every second stage equilibrium involves abatement by at least one firm. The feasible equilibrium set, depicted in Figure 3b, is D"AB". At the point D" all the permits are given to firm 2 while at point B" all are given to firm 1. In the symmetric case, in which the two firms are identical, firms will maximize joint profits by implementing point A. Any other point implies higher output, and since in such a point marginal revenue is lower with constant marginal cost of production and abatement, profits will be lower than at point A. Observe also that even when firms have different abatement cost, joint profits will still be maximized at point A. But in such a case permits will be transferred in such a way that all the abatement will be done by the firm that is more efficient in abatement. Note that at the equilibrium point A the total output level is lower than in any other feasible equilibrium point. If the initial permits do not implement point A, the possibility to trade permits causes a reduction in overall output. Pollution remains at the overall standard so that abatement is also reduced.

In the asymmetric case it is not clear that the firms will indeed choose point A. For example if c_2 is sufficiently large relative to c_1 , firms might choose to move in the direction of B". In such a case output is shifted towards the firm that is more efficient in production. Because firm 2 must do

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[6]A small change in the parameters will not change this result. It might only determine which of the corner points B and D the firms will prefer.

all the abatement on the AB" segment, whereas in point A the firms can have all the abatement done by the more abatement efficient firm, this move is less likely in case $\gamma_1 < \gamma_2$. Note that if production and abatement costs are the same but the emission output ratio α_2 is larger than α_1, the analysis is similar to the case $c_2 > c_1$. In each point on the [AB"] line segment total output is larger than in point A, so it is possible that allowing firms to trade permits implies an increase of overall output. We can conclude the following.

Proposition 4: When the emission output ratio α is the same for the two firms and the overall standard e is such that $A_1 < e/\alpha < B_1$, $A_2 < e/\alpha < D_2$, and $\alpha(A_1 + A_2) > e$, then

(i) in the symmetric case the possibility to trade permits will decrease total industry output, unless the initial permits already implement point A, and lowering the overall standard e will not affect total industry output but will increase abatement

(ii) in case $c_2 > c_1$ and $\gamma_2 \leq \gamma_1$ firms will choose higher total industry output than at point A if $p^0 + 4c_1 - 5c_2 - 2\gamma_1\alpha + \gamma_2\alpha < 0$.

(iii) in case $c_2 > c_1$ and $\gamma_2 > \gamma_1$ firms will choose higher total industry output than at point A if one of the following situations occurs:

(a) $\alpha A_1 < 2\alpha(c_2 - c_1) \leq e$, and $\frac{1}{4}(2(c_2 - c_1) - A_1)^2 > (\gamma_2 - \gamma_1)(\alpha(A_1 + A_2) - e)$

or

(b) $2\alpha(c_2 - c_1) > e$ and $\frac{1}{4}(e/\alpha - A_1)(4(c_2 - c_1) - e/\alpha - A_1) > (\gamma_2 - \gamma_1)(\alpha(A_1 + A_2) - e)$;

in these cases, depending on the initial permits, the possibility to trade permits may decrease but may also increase total industry output, and lowering the overall standard may leave total industry output unaffected but may also decrease output.

Proof: See Appendix. ■

Example 1

Suppose that $p^0 = 20$, $c_1 = 1$, $c_2 = 4$, $\alpha = 1$, $e = 6.5$, $\gamma_1 = 7.33$ and $\gamma_2 = 7.67$. It follows that A = (5,1.67). We are in case iiia which means that if the firms are in A they will trade permits such that output is increased. Maximal joint profits are realized in the feasible equilibrium point (6,1.17). The firm that is less efficient in abatement, firm 2, is abating now, whereas in point A firm 1 can do the abatement. By switching abatement to firm 2 in point A the firms loose 1/18 but the joint gain of moving to point (6,1.17) is 1/4.

It will be clear that similar analyses can be carried out for cases 3c and 3d but that the results will look quite complex. In all these cases the effect of the possibility to trade depends on the initial distribution of permits as well as on the type of asymmetries. We will only give a numerical example.

Example 2

Suppose that $p^0 = 10$, $c_1 = 2$, $c_2 = 3$, $\gamma_1\alpha_1 = 3$ and $\gamma_2\alpha_2 = 0.1$. It follows that C = (3,2), B = (3.033,1.933), D = (1,3) and β = (2.933,2.033).

In case the emission standard is high and the firms are in the Cournot equilibrium C then proposition 3i applies which means that the firms will trade permits such that they end up in a product market equilibrium point between β and D where joint profits are maximal, namely in point (2,2.5). Total output is lower than in C and the price is higher. Because of our assumption on the relative magnitude of α_1 and α_2 overall pollution is also lower than in C, since $\alpha_2 < 2\alpha_1$ implies that $2\alpha_1 + 2.5\alpha_2 < 3\alpha_1$

+ $2\alpha_2$. Firm 1 lowers its output by 1 unit but firm 2 produces 0.5 unit more so that some output is shifted from the low to the high cost firm. One might expect that the equilibrium will not change when the emission standard is lowered as long as the point (2,2.5) remains feasible, but this is not true. Lowering the emission standard might take us to case 3c so that new equilibrium points in the interior and on the line AB become feasible. In fact the firms make higher joint profits in the point (2.1,2.4), which yields the same pollution as the point (2,2.5) in case the emission-output ratios are the same. Note that now some output will be shifted back from the high to the low cost firm.

To summarize, starting with a very high standard, e, and allowing the firms to trade will lead to lower output, lower pollution, no abatement and sometimes even a production shift from the low to the high cost firm. Lowering the standard has initially no effect, which means that existing pollution cannot be reduced in that way. Further lowering the standard, however, either opens up new feasible equilibrium points, like on the interior of B'D' in case 3a, or makes the previous equilibrium non-feasible because the standard becomes too strict. In this stage, or after further lowering the standard, equilibrium points in which at least one of the firms abates become feasible. In the symmetric case the firms will choose either B or D and when B and D are not feasible anymore they choose either B" or D" until these points coincide with A. Further lowering the permits will not change the industry equilibrium output. In the asymmetric case each situation has to be analyzed separately and the outcome depends on the parameter values. However, when the standard becomes very low the equilibrium point is always in A and firms trade permits so that the firm that is less efficient in abatement gets all the permits.

3. The choice of abatement and emission technology

So far we have discussed the interaction between the firms under the assumption that both abatement cost, γ_i, and emission/output ratio, α_i, are given. But if we expand our model to include also the choices of these technologies, we can consider the effect of the possibility to trade pollution permits on the technologies that the firms adopt. Clearly the direct incentive to invest in these technologies is to lower abatement cost. This can be done by lowering the marginal cost of abatement or by reducing the need to abate by lowering the emission/output ratio. But as we have previously showed, abatement cost and emission/output ratio affect the firms' equilibrium profits even when there is no abatement at all. The set of possible equilibria as well as the terms of the trade in permits are affected by γ_i and α_i. Thus in examining the firms' choices of these technologies one should take into account their strategic precommitment values.

In order to illustrate the strategic role of the choice of abatement technology we consider case 2 in which $e_i/\alpha_i > C_i$ for i=1,2 and assume that the firms are symmetric, such that $c_1 = c_2$ and $\alpha_1 = \alpha_2$. The firms have to choose between two types of abatement technologies γ_l and γ_h, such that $\gamma_h > \gamma_l$, and we assume that this choice is costless. The choice of abatement technology takes place after observing the initial emission permits e_i but before the trade in these permits. Similarly we can consider the case in which instead of choosing γ_i firms need to decide (in the same timing) on their emission/output ratio α_i with again a choice between a high value α_h and a low value α_l.

<u>Proposition 5</u>: When the emission permits are sufficiently high then:

(i) in the stage where firms choose their abatement technology γ_i, their dominant strategy is to choose

γ_h, i.e. the inefficient abatement technology; however, the choice of an inferior abatement technology leads to a lower equilibrium pollution level.

(ii) in the stage where firms choose their emission/output ratio α_i, their dominant strategy is to choose the higher one which is more polluting; however, now the choice of an inferior emission/ output ratio leads to a higher equilibrium pollution level.

Proof: (i) The firms' choice of abatement technology affects the feasible equilibrium set. By choosing the technology γ_h firm 1 causes a shift leftward of its full cost reaction function implying that point D will shift to the left on firm 2's upper reaction function. Similarly, firm 2 by choosing γ_h causes a shift down of point B. As was previously analyzed, when the firms have the same production cost, the point that maximizes joint profits is either point B or point D depending on which is closer to the monopolistic points M_1 and M_2. Since the shift left of point D and the shift down of point B both reflect higher joint profits both firms are better off with such a shift. Note also that without the trade in permits the equilibrium continues to be at point C. Thus the choice of an inefficient abatement technology does not affect the status quo point in the bargaining between the firms but it simply yields higher joint profits, which are evenly divided between the firms. Since the choice of inferior abatement technology leads to an equilibrium in which output is lower, it also implies lower overall pollution.

Because high α_i's have similar effects on the feasible equilibrium set the proof of part (ii) follows the same steps. However, in this case overall pollution goes up when α_h is chosen instead of α_l, which can be seen as follows. The difference in pollution is given by $(\alpha_h - \alpha_l)(2(p^0 - c)/3 - \gamma(\alpha_h + \alpha_l)/3)$ and this is always positive. ■

In order to illustrate the other aspects of technology choice we consider case 3b in which $A_1 < e/\alpha_1 < B_1$, $A_2 < e/\alpha_2 < D_2$, $\alpha_1 A_1 + \alpha_2 A_2 > e$, and we further assume that $e/\alpha_i < A_i$. If the only asymmetry between the firms is their abatement and emission technology, the equilibrium will be in point A and all the abatement is done by the firm with the lower γ_i. Note however that the equilibrium point A itself depends on (γ_1,γ_2) but we assume for simplicity that the properties above hold for the all possible realizations of $A(\gamma_1,\gamma_2)$. Consider now the case in which the initial abatement costs are given but firms may invest in reducing these costs. Since in equilibrium only one of the firms does all the abatement the incentives the two firms have to invest in a better abatement technology are not symmetric. First note that if firm 1 lowers its abatement cost, the equilibrium point A moves rightward on the reaction function of firm 2. Such a shift increases the profits of firm 1 and lowers the profits of firm 2 regardless of which firm is doing the abatement. So like in the previous example the first motivation for changing the abatement technology is not necessarily to economize on abatement cost but to manipulate the equilibrium of the product market. It is important to note that in such a case the direction of the incentives is to invest in a better technology while in the previous case we showed that firms are better off with an inferior abatement technology. Since in this case the firms actually abate in equilibrium, economizing on abatement cost serves as another motivation to reduce γ_i. But while only one of the firms does the abatement the investment of the other firm in abatement technology may be viewed as a waste. Given the mechanism of trade we consider in this paper, the money transfer in return for any permits trade depends on the abatement cost as it takes the simple rule of dividing the surplus. In such a case the firm that does not abate has incentives to invest in abatement technology not necessarily in order to put it to use but in order to be in a better bargaining position vis a vis the other firm when they negotiate the terms of the trade. That is if the firm would have lower abatement cost its payment for the permits will be lower. If we assume, as in the previous case, that investment in abatement technology is costless, the incentives to invest are always positive. If investments are costly, a positive optimal level of abatement technology will result.

Proposition 6: When the emission standard and the cost of investment are sufficiently low, both the more and the less abatement efficient firm will invest in abatement technology.

Concluding Remarks

Administrative quotas or permits are usually viewed as inefficient policy instruments. The common wisdom is that some of the inefficiencies may be corrected by allowing trade in those quotas/permits. The main point of this paper is that while this common wisdom may hold in competitive markets one cannot automatically extend it to oligopolistic markets. The paper considers a structure in which both the product market and the permits market are oligopolistic and moreover both markets have the same players. This structure may also be useful in describing other markets like the oligopolistic agricultural market in which each producer has productive quotas and these quotas are tradeable.

Concentrating on oligopolistic markets with tradeable pollution permits the paper demonstrates that allowing trade in emission permits is not necessarily beneficial. In particular it may lead to the choice of inferior production and abatement technologies, it may lead to a market equilibrium with lower output and higher prices and it may result in a shift of production from a low cost to a high cost firm. This, however, does not imply that trade in permits should be banned in oligopolistic markets. One may combine the tradeable permits with other policy instruments to overcome some of the difficulties. For example, a bound on the amount of trade may solve some of the problems that we have identified.

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Appendix:

The set of feasible equilibria in the product market is given by the diamond ABCD where

$$C = \left(\frac{p^0 - 2c_1 + c_2}{3}, \frac{p^0 + c_1 - 2c_2}{3} \right) . \quad \textbf{(6)}$$

$$B = \left(\frac{p^0 - 2c_1 + c_2 + \gamma_2 \alpha_2}{3}, \frac{p^0 + c_1 - 2c_2 - 2\gamma_2 \alpha_2}{3} \right) . \quad \textbf{(7)}$$

$$D = \left(\frac{p^0 - 2c_1 + c_2 - 2\gamma_1 \alpha_1}{3}, \frac{p^0 + c_1 - 2c_2 + \gamma_1 \alpha_1}{3} \right) . \quad \textbf{(8)}$$

$$\frac{p^0 - 2c_1 + c_2 - 2\gamma_1 \alpha_1 + \gamma_2 \alpha_2}{3}, \frac{p^0 + c_1 - 2c_2 + \gamma_1 \alpha_1 - 2\gamma}{3} \quad \textbf{(9)}$$

Note that $c_2 > c_1$ implies $C_1 > C_2$.

Proof of proposition 3:

Joint profits on a line through CB are maximized for

$$q_1^0 = \frac{p^0 - 3c_1 + 2c_2}{2} \quad , \quad q_2^0 = 2(c_1 - c_2)$$

and on a line through CD for

$$q_1^* = 2(c_2 - c_1) \quad , \quad q_2^* = \frac{p^0 + 2c_1 - 3c_2}{2} \quad .$$

Because $c_2 > c_1$ it follows immediately that B is the best point on the line segment [CB]. On the line segment [CD], if $D_1 \leq q_1^* < C_1$ the best point is (q_1^*, q_2^*) and the firms will choose the joint profits at (q_1^*, q_2^*) if these are higher than at point B. This situation happens when $(p^0 - c_2)^2/4 + (c_2 - c_1)^2 >$ $\Pi(B_1,B_2)$, where $\Pi(q_1,q_2) = (p^0-(q_1+q_2))(q_1+q_2)-c_1q_1-c_2q_2$. Straightforward calculation proves part (i). If $q_1^* < D$, the best point is D and the firm will choose this point if the joint profits in D are larger than at B, i.e. $\Pi(D_1,D_2) > \Pi(B_1,B_2)$. Straightforward calculation proves part (ii). ■

Proof of proposition 4:

Recall that on AD" firm 1 abates, on AB" firm 2 abates and in A the more abatement efficient firm abates. Because the emission/output ratio α is the same for the two firms, abatement costs are as if the price is lowered by $\gamma\alpha$.

Joint profits on a line through AD" are maximized for

$$q_1^0 = \frac{p^0 - \gamma_1\alpha - 3c_1 + 2c_2}{3} \quad , \quad q_2^0 = 2(c_1 - c_2)$$

and on a line through AB" for

$$q_1^* = 2(c_2 - c_1) \quad , \quad q_2^* = \frac{p^0 - \gamma_2\alpha + 2c_1 - 3c_2}{2} \quad .$$

Joint profits on a line through AB" in terms of q_1 are given by $-q_1^2/4+(c_2-c_1)q_1+(p^0-\gamma_2\alpha-c_2)^2/4+\gamma_2 e$. In case $c_2>c_1$, it follows immediately that A is the best point on the line segment [AD"] but on the line segment [AB"] it depends. In the symmetric case point A will always be chosen which proves part (i).

If $\gamma_2\leq\gamma_1$, the same firm abates in A and on (AB"] so that the firms will move towards the right of A if $A_1<q_1^*$ which proves part (ii).

If $\gamma_2>\gamma_1$, then firm 1 abates in A whereas firm 2 abates on (AB"].

If $A_1<q_1^*\leq e/\alpha$, the maximal joint profits can be reached on (AB"] and the firms will move towards the right of A if the profit gain $(q_1^* - A_1)^2/4$ outweighs the abatement loss in A given by $(\gamma_2 - \gamma_1)\alpha(A_1 + A_2 - e/\alpha)$, which proves part (iiia),

If $q_1^*> e/\alpha$, maximal joint profits cannot be reached on (AB"] and then the firms will move towards the right of A if the profit gain at B" (note that B_1"$=e/\alpha$) outweighs the abatement loss in A. Straightforward calculation proves part (iiib). ■