INSTITUTE OF MATHEMATICAL ECONOMICS

WORKING PAPERS

No. 219

Equivalence of Effluent Taxes and Permits for Environmental Regulation of Several Local Monopolies

by

Till Requate

April 1993

University of Bielefeld

4800 Bielefeld, Germany

Abstract

We consider n firms, exercising local monopoly power and causing pollution. We show that both kinds of standard policies, taxes and permits, are equivalent if only aggregate pollution matters, regardless of whether the number of monopolies is large or small. (JEL–Classification: L51)

1 Introduction and the Basic Model

It is well known that in a competitive industry with externalities by pollution a perfectly informed regulator can implement the social optimum by imposing a Pigouvian tax on the pollutant or by issuing a number of tradeable effluent permits.

Under imperfect competition on the output market the social optimum can in general not be achieved by pure environmental regulation (see BARNETT [1980], LEVIN [1985]). If, in addition, also the market for permits is not competitive, regulation by taxes or by permits may lead to quite different results, as has been demonstrated recently for different duopoly models in REQUATE [1992,1993].

This paper deals with the polar case to perfect competition. I consider several firms, each of them exercising monopoly power on some local output market, and generating the same kind of pollution. The sum of emissions caused by all the firms generates a negative externality. Typical and most relevant examples are the European utility industries where the firms usually have local monopoly power, and each firm produces at least SO_2, NO_x and other gases responsible for acid rain and dying forests. We assume to have only one pollutant in this paper.

We will show that a suitable Pigouvian tax or a suitable number of tradeable permits are equivalent in order to maintain an aggregate pollution level below the unregulated *laissez-faire* level. As under perfect competition, both policies lead to the same allocation. This may not surprise if the permit market is competitive. But the result does even hold if the number of firms is small such that price taking behavior on a permit market cannot be expected. In this case we assume that the firms negotiate about the allocation of permits and about transfer prices. Since there is no strategic interaction on an output market, the firms have an incentive to achieve the cost efficient allocation of permits among each other, leading to equal abatement costs across the firms. Note that this does not hold in general if firms interact on the output market.

2 Cost and Demand Structure

We consider a partial model. Each of n firms produces an amount q_i of a single commodity and emits an amount e_i of some pollutant which is of the same kind across the firms. The firms' technologies are given by their cost functions $(q_i, e_i) \mapsto C^i(q_i, e_i)$, which are at least C^2 and satisfy $C^i_1 > 0$, $C^i_{11} > 0$, $C^i_{22} > 0$, $C^i_{12} < 0$, so the cost function is convex, output and pollution are complements; furthermore $C_{11}C_{22} > [C_{12}]^2$ (for 2nd order conditions); finally, for each output level there is a unique cost minimizing pollution level $e_i(q_i)$.

Each firm faces a downward sloping inverse demand function P_i which depends on firm i's quantity only and generates a concave revenue function, implying $P_i''(q) < -2P_i'(q)/q$ for all $q > 0$. In the absence of regulation, each firm supplies the monopoly

output q_i^m on its local market and generates the cost minimizing pollution level $e_i(q_i^m)$. Define $E^m := \sum_i e_i(q_i^m)$ as the unregulated emission level.

3 Pigouvian Taxes and Permits for Emissions

Taxes. If the firms' emissions are taxed uniformly by some rate τ, a firm's profit function is given by $\Pi^i(q_i, e_i) = q_iP_i(q_i) - C^i(q_i, e_i) - \tau e_i$. First order conditions for profit maximization yield

$$P_i(q_i) + q_iP_i'(q_i) = C_1^i(q_i, e_i) , \tag{1}$$

$$\tau = -C_2^i(q_i, e_i) , \tag{2}$$

that is, marginal revenue equals marginal cost, and marginal abatement cost is equal to the emission tax. To evaluate the impact of the tax on output and emission of firm i we differentiate (1) and (2) with respect to τ: By virtue of our assumptions on cost and demand we get $e_i' = -1/[C^i_{22} + [C^i_{12}]^2/[P_i''q + 2P_i' - C^i_{11}]] < 0$ and $q_i' = -C^i_{12}/[C^i_{22}[P_i''q+2P_i'-C^i_{11}]+[C^i_{12}]^2] < 0$. Since $e_i(\cdot)$ is decreasing, so is $E(\tau) := \sum_i e_i(\tau)$. Hence, for a given emission level $\overline{E} \leq E^m$ there is a unique tax $\overline{\tau}$ with $E(\overline{\tau}) = \overline{E}$.

Competitive Permit Market. If instead of imposing taxes, effluent permits are issued, and if the number of monopolists is large such that the market of permits is competitive, the situation does not differ from the tax regime. Demand for permits is downward sloping by the same reason as emissions go down when taxes are increased. For a given emission level $\overline{E} \leq E^m$, it is sufficient to issue a number of permits $L = \overline{E}$. If the market price for permits adjusts such that the permits market clears, the price for permits $\sigma(L)$ will equal $\overline{\tau}$.

Non-competitive Permit Market. Let us assume now that no firm behaves as a price taker for permits, and each firm holds some initial endowment of $\hat{l}_i$ permits which allows to dump an amount of $\hat{l}_i$ emissions. Let $L = \sum_i \hat{l}_i$. Holding l_i permits after trade, firm i maximizes its profit $\Pi^i(q_i, e_i)$ s.t. $e_i \leq l_i$. F.o.c.s yield

$$P_i(q_i) + q_iP_i'(q_i) = C_1^i(q_i, e_i) \quad \text{and} \quad C_2^i(q_i, e_i) = 0 , \quad \text{if } e_i \leq l_i, \tag{3}$$

$$P_i(q_i) + q_iP_i'(q_i) = C_1^i(q_i, l_i) , \quad \text{else.} \tag{4}$$

Let $q_i(l_i)$ be the solution of this problem, and let $\tilde{\Pi}^i(l_i) = \Pi^i(q_i(l_i), l_i)$ be the reduced profit function. The firms may trade the permits, however, no Walrasian auctioneer coordinates demand and supply. Hence the few firms have to negotiate about trade. To find a final allocation of permits we have to look for the firms' gain from trade. A reallocation of permits pays if there is an allocation $l = (l_1, \dots, l_n)$ such that $\sum_{i=1}^n \tilde{\Pi}^i(l_i) > \sum_{i=1}^n \tilde{\Pi}^i(\hat{l}_i)$. For in this case there is a vector of transfer payments $T = (T_1, \dots, T_n)$ with $\sum_{i=1}^n T_i = 0$ such that $\tilde{\Pi}^i(e_i) + T_i > \tilde{\Pi}^i(l_i)$ $\forall\, i = 1, \dots, n$. This consideration suggests that the firms will trade the permits such that the final distribution $l = (l_1, \dots, l_n)$ will satisfy $\sum_{i=1}^n \tilde{\Pi}^i(l_i) \geq \sum_{i=1}^n \tilde{\Pi}^i(\tilde{l}_i)$ for all $\tilde{l}$ with $\sum_i \tilde{l}_i = L$.

This allocation determines the Pareto frontier for the firms. What is left to negotiate is the vector of transfer payments. The regulator, who is only interested in the final allocation of permits, does not have to care about the solution concept the firms will employ to figure out these transfer payments. Hence we assume:

Assumption 1 *The firms trade the permits such that the final allocation will solve*

$$\max_{l} \tilde{\Pi}^i(l_i) \quad s.t. \quad \sum_{i=1}^{n} l_i \leq L \,. \tag{5}$$

The Lagrangian for the problem (5) is

$$L(l_1,\ldots,l_n,\lambda) = \sum_{i=1}^{n}[P(q_i(l_i))q_i(l_i) - C^i(q_i(l_i),l_i)] - \lambda[\sum_{i=1}^{n} l_i - L] \tag{6}$$

By virtue of the envelope theorem, the f.o.c.s yield $-C_2^i(q_i(l_i),l_i) = \lambda$. Hence, $\forall i,j = 1,\ldots,n$ we get $C_2^i(q_i(l_i),l_i) = C_2^j(q_j(l_j),l_j)$, which means that marginal abatements costs are the same across the firms. In particular, this implies that the final distribution of permits is independent of the initial distribution. Of course, profits net transfer-payments are not.

Gathering these considerations we have shown:

Proposition 1 *Let the market structure be given as described. If a regulator with sufficient information about the firms' technologies and demand wants to maintain a certain level of aggregate pollution $\overline{E} \leq E^m$, this can be achieved equivalently by imposing a suitable effluent tax or by issuing the corresponding number of permits. Marginal abatement costs are the same for all the firms and each firm produces the same output under taxes as under permits.*

One could ask why the regulator would not fix a price and sell the permits to the firms. Even if he does, it would be necessary to examine the gain from *further* trading permits. Hence we immediately started from a situation where the firms already hold some initial endowment of permits. As a story behind, one can imagine that the government gives an initial endowment, say L/n, to each firm for free in order to avoid cost burdens like environmental taxes.

4 The optimal choice of taxes and permits

Up to now we have only assumed that a certain level of pollution is to be maintained. In order to decide about an "optimal" pollution level, we assume that welfare is additively separable into the sum of consumers' surpluses, minus production costs[1], minus damage from pollution, where the latter is given by a strictly increasing and convex damage function S:

$$W(q_1,\ldots,q_n,e_1,\ldots,e_n) := \sum_{i=1}^{n}\left[\int_0^{q_i} P_i(z)dz - C^i(q_i,e_i)\right] - S(E) \tag{7}$$

Social Optimum It is easy to see that in a social optimum the price equals marginal costs in each market, and abatement costs of each firm equals marginal damage, that is, $P_i(q_i) = C_1^i(q_i,e_i)$, and $S'(E) = -C_2^i(q_i,e_i)$, $\forall i = 1,\ldots,n$, where $E = \sum_{i=1}^n e_i$.

Optimal taxation. Taking q_i and e_i as a function of τ we write $\widetilde{W}(\tau) := W(q_1(\tau),\ldots,q_n(\tau),e_1(\tau),\ldots,e_n(\tau))$. Employing (1) and (2) we get:

$$\begin{aligned} \frac{d\widetilde{W}}{d\tau} &= \sum_{i=1}^{n}\left[P_i(q_i) - C_1^i(q_i,e_i)\right] q_i' - \sum_{i=1}^{n} C_2^i(q_i,e_i)e_i' - S'(E)\sum_{i=1}^{n} e_i' \\ &= -\sum_{i=1}^{n} P_i(q_i)q_i q_i' - \sum_{i=1}^{n}[-\tau + S'(E)]e_i' \stackrel{!}{=} 0 \end{aligned} \tag{8}$$

Setting $E' = \sum_{i=1}^n e_i'$ and solving for τ yields for $i = 1,\ldots,n$:

$$-C_2^i(q_i,e_i) = \tau = S'(E) + \frac{\sum_{j=1}^n P_j'(q_j)q_j q_j'}{E'} \,. \tag{9}$$

Since $P_j' < 0$ by assumption and $q_j' < 0$, $e_j' < 0$, as shown, we get $\tau < S'(E)$. Clearly, the tax must be less than marginal damage since in the absence of regulation, firms produce less than in social optimum.

Optimal number of permits. Taking q_i, l_i and welfare as a function of the number of permits L, similar calculations lead us to

$$-C_2^i(q_i,e_i) = \lambda = S'(L) + \sum_{j=1}^{n} P_j'(q_j)q_j q_j' \tag{10}$$

for each i, where λ is the Lagrange multiplier of the permit constraint $\sum_j l_j \leq L$. Since $q_i(L) = q_i(\tau)$ and $l_i(L) = e_i(\tau)$, we get $\lambda = \tau$.

Clearly the social optimum cannot be achieved by pure pollution control since firms go on to behave monopolistically on the output market.

5 Simultaneous Regulation of Output and Emissions

As Cropper and Oates [1992] point out, environmental authorities usually neither have the information nor the power to regulate imperfections on the output market. On the other hand, under perfect information, monopoly can be induced to produce

[1] We give equal weight to each market since we assume that the inverse demand function reflects the size of each market.

the social optimum by subsidizing output. If some other authority subsidizes output by the rate σ, and pollution is taxed by τ, the firms face the following profit function:

$$\Pi^i(q_i, e_i) = q_i[P_i(q_i) + \sigma] - C^i(q_i, e_i) - \tau e_i \tag{11}$$

f.o.c.s of profit maximization yield

$$P(q) + qP'(q) + \sigma = C_1^i(q, e) \, , \tag{12}$$
$$\tau = -C_2^i(q, e) \, . \tag{13}$$

If regulators can impose individual subsidies in each market — which could be the case if the products are different or local (state) governments can pay different subsidies, the following is easy to show:

Proposition 2 *If individual subsidies σ_i can be paid in each product market, the social optimum can be implemented by paying a subsidy of*

$$\sigma_i = -\frac{P_i'(q_i)}{q_i} \tag{14}$$

in each market, and *<u>either</u>* *taxing pollution uniformly by a rate of*

$$\tau = -C_2^i(q_i, e_i) \, , \tag{15}$$

<u>or</u> *by giving out a number of permits such that the shadow price of pollution equals*

$$\lambda = -C_2^i(q_i, e_i) \, . \tag{16}$$

References

BARNETT, A.H. (1980): "The Pigouvian Tax Rule under Monopoly," *American Economic Review*, 70, 1037 – 1041

BAUMOL, W.J., W.E. OATES (1988): *The Theory of Environmental Policy*, Cambridge, MA: Cambridge University Press

CROPPER, M.L., W.E. OATES (1992): "Environmental Economics: A Survey," *Journal of Economic Literature*, 30, 675–740

LEVIN, D. (1985): "Taxation within Cournot Oligopoly," *Journal of Public Economics*, 27, 281–290

REQUATE, T. (1992): "Pollution Control under Imperfect Competition via Taxes or Permits: Cournot Duopoly," *University of Bielefeld, Institute of Mathematical Economics, Disc. Paper* No. 212

REQUATE, T. (1993): "Pollution Control under Imperfect Competition: Asymmetric Duopoly with Linear Technologies," *Journal of Institutional and Theoretical Economics*, 149, 415–442