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EMISSION TAXES AND THE DESIGN OF REFUNDING SCHEMES

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Abstract

We examine how emission taxes should be refunded to firms in order to create optimal incentives to invest in cleaner technologies. Since refunds cannot be made dependent on investments, an alternative way is to give back taxes to firms according to market shares. We show that universally applicable refunding schemes must be linear in market shares. Moreover, a socially optimal tax/tax refunding scheme exists if pollution is proportional to output and firms compete à la Cournot. If short-term abatement technologies exist, tax/tax refunding schemes can still provide second-best allocations. If firms are price takers, however, refunding taxes according to market shares is harmful. Since imperfect competition is a prominent phenomenon in many polluting industries, the design of socially optimal refunding schemes is an essential part of environmental regulation.

JEL Classification: L5, Q2, Q28

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1 Introduction

While the United States use tradeable permits to control air pollution, notably from SO_2 and NO_x, many European countries have decided to levy taxes on air pollutants. In particular, Norway, Sweden, Denmark, the Netherlands, and France have introduced taxes on SO_2 and, except for the Netherlands, also on NO_x. Denmark, the Netherlands, Norway, Finland and Slovenia impose taxes on CO_2.[1] In all these cases the question arises of what to do with the tax revenues. Some countries do not earmark those revenues for any particular purpose but add them to the state's budget. Denmark uses the revenues partially to subsidize the firms' share of social security payments. While France subsidizes firms' investments in advanced abatement technology and monitoring equipment, Sweden fully refunds emission taxes on NO_X to firms according to market shares.

In this paper, we investigate how refunding schemes can and should be designed to create incentives for firms to invest in cleaner technologies. There are basically two ways the regulator can make refunds dependent on the activities of firms. First, refunds could depend on the investment efforts in clean technologies. However, even if investments by firms can in fact be observed by the regulator, it is difficult to verify investment in court as discussed by the incomplete contract literature (e.g. Hart 1996). Moreover, investment in integrated environmental technology can frequently not be clearly separated from investments for cutting costs or increasing capacity. Therefore it is difficult, if not impossible, to allocate refunds according to investment in clean technologies.

Second, refunds could depend on the output or market shares of a firm, these after all being both observable and verifiable. Inspired by the incomplete contract argument and the Swedish example, we follow this latter approach and allow for a regulator using market shares to refund a certain portion of tax revenues to the industry. In the first step we characterize all possible refunding schemes which depend on market shares. We show that a scheme paying a fixed share of the tax revenues back to the firms and universally applicable to any distribution of market shares must be linear. This is a convenient property and simplifies further analysis.

Then we ask how much of the tax revenues should be refunded under imperfect (Cournot) and perfect competition. Our major conclusions are: first, for symmetric Cournot oligopoly with pollution proportional to output (i.e. only long-term abatement technologies exist), there exists a tax/tax refunding scheme leading to a first-best

1 An excellent survey of the current taxation of air pollutants in all of the countries mentioned is given by Cansier and Krumm (1997).

outcome (i.e. first-best pollution with first-best investment levels) unless the damage from pollution is extremely low. A portion of the tax revenues is refunded. The optimal share of taxes given back to firms is decreasing in the marginal damage from pollution. In some cases, it can be optimal to tax emissions and have reverse refunding, i.e. market shares are taxed as well.

Second, if short-term abatement is possible without reducing output, first best tax/tax refunding schemes do not exist. The reason is that the government has only two instruments for regulating three market imperfections: firms hold down output, they pollute too much per unit of output, and they overinvest strategically in order to increase their market shares. Nevertheless, refunding can help to bring investment incentives closer to first-best levels.

Third, if firms are price takers, the optimal refunding share is zero, i.e. firms should not get refunds according to their market shares. Rather, taxes should either be refunded in a lump sum way if no further distorting taxes exist, or tax revenues should be used to finance the state budget if distorting taxes exist elsewhere.

Taking all conclusions together we can conclude that the nature of competition determines whether refunding should be used at all. Since imperfect competition is prevalent in many industries where emission taxes are employed, the design of the optimal share of tax revenues to be refunded appears to be an essential part of environmental regulation. Moreover, as we will discuss in the final section, refunding emission taxes may help to overcome political resistance to environmental regulation.

In section 2 of the paper we provide a survey of related literature. In section 3 we set up a model. Section 4 characterizes socially optimal allocations. In section 5 we describe the timing of regulation and the firm's behavior. We show that in order to satisfy certain desired properties refunding schemes must be linear. In section 6 we characterize optimal tax/tax refunding schemes for Cournot oligopoly if pollution is proportional to output. In section 7 we show that the tax/tax refunding scheme fails to implement first-best in cases where short-term abatement technologies exist. Section 8 deals with perfect competition while section 9 summarizes our conclusions and discusses further implications. Proofs are given in the appendix.

2 Related Literature

Countries that use emission taxes have employed very different approaches to the use of tax revenues. As discussed and surveyed in Cansier and Krumm (1997) a number of political and economic motives can be singled out to explain the heterogeneity of approaches. In our paper we discuss refunding schemes from a welfare point of view. The Swedish example suggests that the refunding scheme discussed in this paper can actually be applied in practice.

With respect to the theory our paper is related to the literature on environmental regulation and in particular to the work on strategic considerations of firms' behavior (Yao 1988, Malik 1991, Biglaiser, Horowitz and Quiggin 1995, Gersbach and Glazer 1999). The overall conclusion of this line of research is that the strategic behavior of firms against the regulator normally makes it impossible to achieve the social optimum.[2] Our analysis suggests that refunding schemes according to market shares can eliminate or alleviate the inefficiencies in imperfectly competitive markets.

Finally, our paper is related to work on the incentives for adopting less polluting technologies in the design of environmental policy instruments. Milliman and Prince (1989) and Jung, Krutilla, and Boyd (1996) examine the incentives for firms to invest in new technology under different regulatory methods and provide a ranking of different policy instruments. Laffont and Tirole (1996) show that simple markets for pollution permits reduce incentives for innovation, and propose options to pollute as a better policy. Requate (1995) considers output markets and shows that permits allow for partial adoption of new technologies while taxes do not. Requate and Unold (1997) challenge the general presumption that permit markets provide higher incentives to innovate than taxes. Our analysis suggests that under imperfect competition the social efficiency of emission taxes can be improved to the first-best levels if long-term abatement technologies exist. Hence, without an explicit consideration of refunding schemes for emission taxes any comparison of permit markets and emission taxes is incomplete as far as imperfectly competitive markets are concerned.

2 Gersbach and Glazer (1999), however, show that permit markets can achieve a first-best allocation when firms compete to become suppliers of permits and to benefit from selling permits. Moreover, Gersbach (1996) shows that a tax/subsidy scheme can help to overcome investment hold–up problems when investing firms receive subsidies from the taxation imposed on non–investing firms.

3 Model

Throughout this paper we consider a partial model with one consumption good and one pollutant generated by production. The good is produced by $n \geq 2$ quantity setting firms engaged in Cournot competition. Let q_i and e_i denote the output and emissions of firm $i = 1, \ldots, n$, respectively. Society's preferences are derived from an inverse demand function and from a social damage function, denoted by S. Inverse downward sloping demand $P(\cdot)$ depends on aggregate output $Q = \sum_{i=1}^{n} q_i$ and satisfies

$$-\frac{P''(Q)Q}{P'(Q)} < 1. \tag{1}$$

This assumption guarantees that inverse demand is not too convex.[3] The social damage function depends on aggregate emissions $E = \sum_{i=1}^{n} e_i$ and is increasing and convex in the total amount of emissions produced by the industry, i.e. $S' > 0$, $S'' > 0$.

3.1 Long-Run Abatement Technologies

In the first variation of our model we assume that pollution is completely determined by the output when firms enter the production stage. The firms have access to a family of pollution technologies which they can invest in before they enter production. Specifically, we assume that if firm i chooses ν_i to reduce pollution, its emissions are given by

$$e_i = (\bar{\nu} - \nu_i)q_i.$$

$\bar{\nu}$ denotes the emission per units of output when no investments in clean technologies take place. $K(\nu_i)$ is the corresponding investment cost. We assume decreasing marginal returns on investments in clean technologies. That is

$$K' > 0, K'' > 0. \tag{2}$$

We assume that marginal production costs are constant or increasing and independent of investments in cleaner technologies, i.e. $C(q_i) > 0$, $C'(q_i) > 0$ and $C''(q_i) \geq 0$.[4]

3 Usually $-P''(Q)Q/P'(Q)$ is assumed to not exceed 2 in order to guarantee stability of Cournot Nash equilibrium. We need a slightly stronger condition here.

4 This assumption is mainly made for tractability reasons. Marginal costs could also depend on ν_i. As long as C does not vary much with ν_i, our results remain qualitatively unaffected.

3.2 Short Run Abatement Technologies

In the second variation of the model we assume that firms can reduce emissions without reducing output when they enter the production stage because they also have access to abatement technologies in the short run. Their technologies are represented by their cost functions $C(q_i, e_i, k_i)$ where k_i is the firm's level of investment in dollars. We assume increasing marginal cost, i.e. $C_q > 0$, $C_{qq} > 0$. Moreover, $-C_e > 0$ and $C_{ee} > 0$, which means that marginal abatement costs are positive and increasing with fewer emissions. Furthermore, we have $C_{qe} < 0$, or equivalently $-C_{eq} > 0$, which means that marginal costs are decreasing with more emissions, or marginal abatement costs are increasing with more output, respectively. Additionally, we have $C_k < 0$, $C_{qk} < 0$, $-C_{ek} < 0$, which means that costs, marginal costs of production, and marginal abatement cost are decreasing with higher investment, but $C^i_{kk} > 0$, i.e. we have decreasing returns on investment. Finally, we assume that the cost function is convex.

4 The Social Optimum

We shall now analyze the properties of socially optimal allocations, first for long-term then for short-term abatement technologies.

4.1 Long Run Abatement Technologies

Where pollution is completely determined by output and choice of technology, i.e. investment ν_i, welfare is given by

$$W(q_1, ..., q_n, \nu_1, ..., \nu_n) = \int_0^Q P(\tilde{Q})d\tilde{Q} - \sum_{i=1}^{n} C(q_i) - \sum_{i=1}^{n} K(\nu_i) - S(E)$$

where $E = \sum_{i=1}^{n}(\bar{\nu} - \nu_i)q_i$ denotes total emissions. The first-order conditions for the socially optimal allocation, given by a symmetric allocation $q_i = q$ and $\nu_i = \nu$, is determined by:

$$P(Q) = C'(q) + (\bar{\nu} - \nu)S'(E) \tag{3}$$

$$qS'(E) = K'(\nu) \tag{4}$$

The well-known condition (3) states that the marginal willingness to pay for the commodity should be equal to the private marginal cost plus the external marginal cost. Equation (4) says that marginal damage multiplied by a firm´s output must be equal to marginal cost of investment. Note that these two equations simultaneously determine output q and the technology parameter ν. Our assumptions on P, S and K guarantee that the second order conditions are also satisfied. We use q^* and ν^* to denote socially optimal output and emission reduction. The socially optimal aggregate output nq^* is denoted by Q^*.

4.2 Short-Run Abatement Technology

Given that abatement is possible, welfare is expressed by

$$W(q_1, ..., q_n, e_1, ..., e_n, k_1, ..., k_n) = \int_0^Q P(\tilde{Q})d\tilde{Q} - \sum_{i=1}^{n} C(q_i, e_i, k_i) - \sum_{i=1}^{n} k_i - S(E)$$

where now $E = \sum_{i=1}^n e_i$. The first-order conditions in the symmetric case where each firm invests the same amount in pollution reduction and produces the same amount, i.e., $q_i = q$, $e_i = e$, and $k_i = k$, are now given by

$$C_q(q, e, k) = P(Q) \quad (5)$$
$$-C_e(q, e, k) = S'(E) \quad (6)$$
$$-C_k(q, e, k) = 1 \quad (7)$$

The conditions state that a) marginal willingness to pay equals marginal costs, b) marginal abatement costs are equal to marginal damage, and c) marginal cost reduction through investment is equal to its dollar value of 1.

5 Regulation and Refunding Schemes

Our main assumption is that regulators cannot directly force firms to invest – e.g. by punishing them for not investing – because investments are not verifiable. This is obvious if investments consist of R&D activities or investment in integrated environmental technologies which cannot be separated from other business investments. Hence, the only way for regulators to provide investment incentives for firms is to set lower or higher tax rates and to design the refunding scheme accordingly.

The government levies a uniform tax τ on emissions and designs a refunding scheme for revenues from emission taxes. Using the approach to NO_X-taxation adopted in Sweden, the government can make refunding dependent on market shares. The refund to a firm i is denoted by R_i and is given by

$$R_i = R\left(\frac{q_i}{Q}\right)T$$

where T denotes total tax revenues given by $T = \tau E$. $R(\frac{q_i}{Q})$ denotes the share of tax revenues refunded to a firm with market share $\frac{q_i}{Q}$.[5] Deviating from the Swedish example, we allow for the refunding scheme to not necessarily completely exhaust the budget generated by taxes. We denote by $d \in [0,1]$ the share of tax revenues the regulator decides to refund to firms. In the case $d = 1$, all tax revenues are channeled back to firms. We call $d = 1$ *total refunding*. Therefore, the budget constraint of the government implies:

$$\sum_{i=1}^{n} R\left(\frac{q_i}{Q}\right) = d \qquad \text{where } d \in [0,1].$$

We now define the game between the regulator and the firms in more detail. The timing for long-run abatement technologies is as follows:

Stage 1: The regulator sets the emissions tax and chooses the percentage of tax revenues refunded to firms, i.e. chooses a parameter $d \in [0,1]$.

Stage 2: The firms invest and choose a technology ν_i.

Stage 3: The firms engage in Cournot competition by choosing q_i,
pay emission taxes τe_i,
and receive refunds R_i according to their market share.

When abatement technologies are also short-run, i.e. firms can reduce emissions at the production stage without reducing output, the regulatory mechanism is as follows:

Stage 1: The regulator sets the emissions tax and chooses the percentage of tax revenues refunded to firms, i.e. chooses a parameter $d \in [0,1]$.

Stage 2: Firms choose k_i.

Stage 3: Firms choose q_i and e_i.

Firms pay emission taxes τe_i
and receive refunds R_i according to their market share.

Next we determine the set of feasible refunding schemes. Every uniformly applicable refunding system must fulfill three conditions. First, it must satisfy universal domain, i.e. be applicable to every possible constellation of market shares. Second, $R(0)$ must be zero, otherwise firms could claim refunds even if they are not active. Third, aggregate

5 Following the real-world example in Sweden, we assume that the refund to firm i depends only on its market share and not on the market share of other firms.

refunds must be equal to the share d of revenues from emission taxes which the regulator wants to channel back to the firm. These two conditions limit the set of refunding schemes to just one possibility.[6] We obtain:

Proposition 1

Suppose that $n > 2$. Then a uniformly applicable refunding scheme where the regulator refunds a share $0 < d \leq 1$ of total tax revenues must satisfy

$$R\left(\frac{q_i}{Q}\right) = d\frac{q_i}{Q}$$

The proof is given in the appendix. Proposition (1) indicates that this kind of regulation is limited by linear refunding schemes. Non-linear refunding schemes are ruled out by two reasons. First, $R(0)$ must be zero as required above. Second, non-linear refunding schemes would violate the budget constraint if market shares of firms are concentrated in areas where refunds per unit of market shares are particularly high. In the following, we will use the linear refunding scheme to examine how incentive investments by firms react to refunding schemes.

Note that in case of $n = 2$ non-linear refunding schemes are possible, but are not necessary to reach first-best allocations. It is also obvious that in the case of a monopoly refunding does not make sense since it simply amounts to a reduction of emission taxes. Hence, the tax/tax-refunding policy problem is restricted to oligopolies.

6 Optimal Tax/Refunding Schemes for Long-term Abatement Technologies

We first examine refunding schemes where only long-term abatement technologies exist. In the whole section we assume $n \geq 2$. The firms' profits are given by

$$\pi(q_i, \nu_i) = [P(Q) - \tau(\bar{\nu} - \nu_i)]q_i - C(q_i) - K(\nu_i) + d\frac{q_i}{Q}\tau\sum_{k=1}^{n}(\bar{\nu} - \nu_k)q_k$$

We solve the game backwards. A firm´s first-order condition in the last stage is given by

$$P'(Q)q_i + P(Q) - C'(q_i) - \tau\left[\left(1 - d\frac{q_i}{Q}\right)(\bar{\nu} - \nu_i) - d\frac{Q - q_i}{Q^2}\sum_{k=1}^{n}(\bar{\nu} - \nu_k)q_k\right] = 0 \quad (8)$$

6 Note that we have assumed that R_i should only depend on $\frac{q_i}{Q}$. If this is not the case, the set of feasible refunding schemes may be larger.

In a symmetric equilibrium with $q_i = q$, $Q = nq$ and $\nu_i = \nu$ the term in brackets becomes

$$(\bar{\nu} - \nu)\left[1 - d\left(\frac{1}{n} + \frac{n-1}{n}\right)\right] = (\bar{\nu} - \nu)(1-d)$$

Thus the Nash-equilibrium condition in a symmetric equilibrium reduces to a single equation:

$$P'(nq)q + P(nq) - C'(q) - \tau(\bar{\nu} - \nu)(1-d) = 0 \tag{9}$$

From equation (9) we immediately derive the following result:

Proposition 2

Suppose that tax revenues are fully refunded, i.e. $d = 1$, then the firms' output choice in the third stage is independent of the tax rate.

Proposition 2 implies an important separation property. Introducing arbitrary levels of emission taxes with complete refunding does not affect output and therefore does not change the wedge between marginal production costs and prices. Using equation (9) comparative statics of equilibrium output for $d < 1$ in the third stage with respect to the tax rate yields

$$\frac{\partial q}{\partial \tau} = \frac{(\bar{\nu} - \nu)(1-d)}{n\,P''q + (n+1)\,P' - C'(q)}$$

which is smaller than zero by assumption (1). Similarly, we have

$$\frac{\partial q}{\partial d} = \frac{-\tau(\bar{\nu} - \nu)}{n\,P''q + (n+1)\,P' - C'(q)} > 0$$

The effect of a change in ν_i on the equilibrium quantities in the subgame of the third stage is not so easy to obtain as we cannot simply differentiate the symmetric equilibrium condition (9) with respect to ν, the reason being that a unilateral change of ν_i causes an asymmetric equilibrium in the subgame of the third stage.

Hence we have to differentiate (8) with respect to ν_i. The expressions for the terms $\partial q_i/\partial \nu_i$ are complicated and difficult to sign in general. For d sufficiently close to zero, however, one can show that $\partial q_i/\partial \nu_i > 0$ and $\partial q_j/\partial \nu_i < 0$ for $j \neq i$. The intuition for this result is clear. Higher investment into ν_i reduces the variable cost in the third stage of the game. It is well known that in a Cournot equilibrium the market share of firm i grows if its marginal cost falls while the market shares of competitors shrink. As we will see, we do not need to know the precise expressions for $\partial q_j/\partial \nu_i$.

We now consider the **second stage** of the game. A firm maximizes its profit w.r. to ν_i. By virtue of the envelope theorem the first order condition reads

$$\frac{d\pi}{d\nu_i} = \frac{\partial \pi}{\partial \nu_i} + \sum_{k \neq i} \frac{\partial \pi}{\partial q_k} \cdot \frac{\partial q_k}{\partial \nu_i} \tag{10}$$

We obtain:

$$\begin{aligned} \frac{d\pi}{d\nu_i} &= \tau \left[1 - d\frac{q_i}{Q}\right] q_i - K'(\nu_i) \\ &+ q_i P'(Q) \sum_{j \neq i} \frac{\partial q_j}{\partial \nu_i} - \tau d \frac{q_i}{Q} \left[\frac{q_i}{Q} \sum_{j \neq i} \frac{\partial q_j}{\partial \nu_i} (\overline{\nu} - \nu_i) - \sum_{j \neq i} \frac{\partial q_j}{\partial \nu_i} (\overline{\nu} - \nu_j) \right] \\ &- \tau d \frac{q_i}{Q^2} \sum_{j \neq i} (\overline{\nu} - \nu_j) q_j \cdot \sum_{j \neq i} \frac{\partial q_j}{\partial \nu_i} = 0 \end{aligned} \tag{11}$$

In a symmetric equilibrium we get $\nu_i = \nu$ for all i and $\partial q_j/\partial \nu_i = \partial q_k/\partial \nu_i$ for all $j \neq i$ and $k \neq i$, and $q_i = q, Q = nq$. Thus (11) becomes

$$\begin{aligned} K'(\nu) = \tau \Big[1 - d\frac{q}{Q}\Big] q - \tau d(\overline{\nu} - \nu) \frac{\partial q_j}{\partial \nu_i} \frac{q}{Q} (n-1) \Big[\frac{q}{Q} - 1 + \frac{1}{Q}(n-1)q\Big] \\ + (n-1) P'(Q) q \frac{\partial q_j}{\partial \nu_i} \end{aligned}$$

Since the term in the second bracket is zero, the first order condition in symmetric equilibrium reduces simply to

$$K'(\nu) = \tau(1 - \frac{d}{n})q + (n-1)P'(Q)q\frac{\partial q_j}{\partial \nu_i} \tag{12}$$

Finally, we solve the **regulator's problem**. He maximizes welfare with respect to the tax rate τ and the share of refunding d. Subject to the constraint

$$0 \leq d \leq 1 \tag{13}$$

welfare in a symmetric equilibrium is given by:

$$W(q, \nu) = \int_0^Q P(z)dz - nC(q) - nK(\nu) - S(ne) \tag{14}$$

Let s denote the policy variable, i.e. $s \in \{\tau, d\}$. Ignoring the constraint (13) for a moment, i.e. assuming an interior solution, the regulator's first-order condition with respect to s becomes

$$\frac{\partial W}{\partial s} = [P(Q) - C'(q)] \frac{\partial Q}{\partial s} - n\frac{K'(\nu)\partial\nu}{\partial s} - S'(E) \left[(\overline{\nu} - \nu)\frac{\partial Q}{\partial s} - Q\frac{\partial \nu}{\partial s}\right] \tag{15}$$

$$= [P(Q) - C'(q) - S'(E)(\bar{\nu} - \nu)] \frac{\partial Q}{\partial s} - [nK'(\nu) - S'(E)Q] \frac{\partial \nu}{\partial s} = 0 \tag{16}$$

Since this must hold for both $s = \tau$ and $s = d$, to achieve a first best allocation it is sufficient for the two terms in square brackets to be equal to zero. Therefore, $P(Q) - C'(q) - (\overline{\nu} - \nu)S'(E) = 0$ and $q\, S'(E) = K'(\nu)$, which correspond to the conditions of the socially optimal allocation. Using the symmetric equilibrium conditions (9) and (12), and rearranging now yields:

$$-P'(Q)q + \tau(\overline{\nu} - \nu)(1 - d) - (\overline{\nu} - \nu)S'(E) = 0 \tag{17}$$

$$\tau(1 - \frac{d}{n})q + (n-1)P'(Q)\frac{q\partial q_j}{\partial \nu_i} - q\, S'(E) = 0 \tag{18}$$

Thus we obtain the two conditions

$$\tau = \frac{n}{n-d}\left[S'(E) - (n-1)P'(Q)\frac{\partial q_j}{\partial \nu_i}\right] \tag{19}$$

and

$$(1-d)\tau = \left[S'(E) + \frac{P'(Q)\cdot q}{(\overline{\nu} - \nu)}\right] \tag{20}$$

Eliminating τ from (19) and (20) and solving for d yields

$$d = \frac{P'(Q)Q + (n-1)nP'(Q)\cdot \frac{\partial q_j}{\partial \nu_i}(\overline{\nu} - \nu)}{(1-n)S'(E)(\overline{\nu} - \nu) + P'(Q)q + (n-1)nP'(Q)\frac{\partial q_j}{\partial \nu_i}(\overline{\nu} - \nu)} \tag{21}$$

or

$$d = \frac{\dfrac{Q}{\overline{\nu} - \nu} + (n-1)n\dfrac{\partial q_j}{\partial \nu_i}}{\dfrac{q}{\overline{\nu} - \nu} + (n-1)n\dfrac{\partial q_j}{\partial \nu_i} - (n-1)\dfrac{S'(E)}{P'(Q)}} \tag{22}$$

Equations (19) and (21) determine the optimal tax rate, denoted by τ^*, and the optimal refunding share, denoted by d^*, respectively. In order to keep the system self-financing, three cases are possible. First, the optimal tax rate τ^* is positive and d^* does not exceed 1. Second, τ^* is positive but d^* is negative, which means that in addition to taxing emissions the market share is also subject to a tax. Third, the tax rate may even be negative, i.e. it is a subsidy, and d^* is greater than 1, which means that the market share is subject to a tax $-\tau^* d^* > 0$. Note that for $\tau^* < 0$, the condition $d^* > 0$ means that market shares are taxed because a negative amount of money is refunded. Self-financing requires that $d^* > 1$ and thus tax revenues from taxing market shares be higher than $-\tau^* E$.

In order to examine the circumstances under which a first-best allocation is possible with a self-financing tax/tax-refunding scheme, we consider the following expressions:

$$A = S'(E^*) + \frac{P'(Q^*)q^*}{(\bar{\nu} - \nu^*)} \tag{23}$$

$$B = \frac{-P'(Q^*)Q^*}{(\bar{\nu} - \nu^*)} \left\{ \frac{1}{n-1} + \frac{\partial q_i}{\partial \nu_j}\Big|_{\nu_i = \nu_j = \nu^*} \frac{\bar{\nu} - \nu^*}{q^*} \right\} \tag{24}$$

If $A \geq 0$ this implies that the marginal damage from pollution is more severe than the distortion through imperfect competition. In a traditional model of taxing emissions in oligopoly without pre-investment, this condition is necessary and sufficient for the (second-best) optimal tax rate to be non-negative. If B is positive in equation (24), this means that the elasticity of a firm i's output change is not too large if a different firm j decreases pollution per output. Observe that $-\partial q_i / \partial(\bar{\nu} - \nu_j) = \partial q_i / \partial \nu_j < 0$. To prepare our main result, we first relate the optimal tax rate and the refunding share to the expressions introduced in (23) and (24).

Lemma 1

The optimal tax rate τ^*, the refunding share d^*, and the effective tax rate $(1 - d^*)\tau^*$ can be written as:

$$\begin{aligned} \tau^* &= A + B \\ d^* &= \frac{B}{A + B} \\ (1 - d^*)\tau^* &= A \end{aligned} \tag{25}$$

The proof of lemma 1 is given in the appendix. The next proposition provides necessary and sufficient conditions for the existence of a first-best, self-financing tax/tax-refunding scheme.

Proposition 3

Suppose that $A \geq 0$. There then exists a first-best and self-financing tax/tax-refunding scheme. Either $\tau^* \geq 0$ and $d^* \leq 1$ holds, or $\tau^* < 0$ and $d^* > 1$. If $A < 0$ no self-financing first-best tax/tax-refunding scheme exists.

Proof :
From lemma 1 we have $(1 - d^*)\tau^* = A$. $(1 - d^*)\tau^*$, however, is just the net money transfer per emission unit from the industry to the state budget. If A is positive, the net transfer is positive and self-financing is possible. Two cases are conceivable. First $\tau^* \geq 0$ which requires $d^* \leq 1$. In this case emissions are taxed and a portion of these taxes is refunded. Second, $\tau^* < 0$, which requires $d^* > 1$. In this case emissions are subsidized and market shares are taxed to pay for the subsidy. $d^* > 1$ is needed to make the system self-financing. Since τ^* and d^* satisfy the optimality conditions (20) and (21) the allocations are first-best. If $A < 0$, self-financing is impossible since the net transfer to the state budget for the optimal values τ^* and d^* is negative.

■

Now we are able to characterize immediately all constellations τ^* and d^* as follows:

Proposition 4

(i) Suppose $A + B \geq 0$ and thus $\tau^* \geq 0$. Then

$$d^* \geq 0 \text{ if and only if } B \geq 0,$$

(ii) Suppose $A + B < 0$ and thus $\tau^* < 0$. Then

$$d^* \geq 0 \text{ if and only if } B \leq 0,$$

Note that proposition 4 covers both cases, $A \geq 0$ and $A < 0$. In the latter case, however, self-financing is not possible. An immediate implication of propositions 3 to 4 is:

Corollary 1 *If $S'(E^*) = -\frac{P'(Q^*)q^*}{(\overline{\nu}-\nu^*)}$, there exists a first-best tax/tax-refunding scheme with complete refunding, i.e., $\tau^* \geq 0$ and $d^* = 1$.*

The preceding propositions have a number of interesting implications. First, the positive implication of proposition 3 is that severe environmental problems, i.e. pollution with high marginal social damage ($A > 0$), are best suited to the use of refunding schemes. If the marginal social damage is sufficiently high, there exists a first-best tax/tax-refunding scheme. Higher marginal social costs from emissions will raise, ceteris paribus, both emissions tax and the incentives to invest in clean technologies. Moreover, a larger amount of taxes can be refunded, which allows for the creation of first-best incentives for output choices. Note, however, that it may be optimal to refund only a certain portion of the tax revenues.

Second, in the case where $A > 0$ and $A+B > 0$, the net tax rate $\tau(1-d)$ is smaller than marginal social damage and satisfies the well-known tax rule for imperfectly competitive firms established by Barnett (1980) and Ebert (1992).

Third, some other implications are quite surprising. If $A > 0$, $A+B > 0$ and $B < 0$ it transpires that taxation of both emissions and market share is the optimal course. If, furthermore, the marginal damage is not very high (i.e. $A > 0$ but $A+B < 0$), then a reversal of the Swedish tax/refunding scheme is optimal. Market share is taxed to use the revenues for subsidizing emissions, and some revenues may still be used for other purposes. Note that $A+B < 0$ cannot be assumed away since because in equation (19) $\partial q_j/\partial \nu_i$, firm $j's$ output reaction on firm $i's$ improvement of technology can be quite strong.

Fourth, if the marginal damage is low, i.e. $A < 0$, the oligopolistic distortion of too little production is stronger than the distortion by pollution. In this case industries should be subsidized rather than being taxed on a net base. A first-best allocation could only be achieved by paying subsides from the state budget or by raising lump-sum taxes. However, even in this case emission taxes may be positive, provided that B is sufficiently positive.

7 Optimal Tax/Refunding Schemes for Short-Term Abatement Technologies

With short run abatement opportunities the firms' profit is given by

$$\pi(q,e,k) = P(Q)q_i - C(q_i,e_i,k_i) - k_i - \tau e_i + d\frac{q_i}{Q}\tau\sum_{i=1}^{n} e_i$$

The first-order condition in a symmetric Nash equilibrium in the third stage is given by

$$P'(Q)q + P(Q) - C_q + \frac{n-1}{n}\tau d \frac{e}{q} = 0 \tag{26}$$

$$-C_e = \tau \tag{27}$$

In the second stage firms choose investment. The first-order condition in Nash equilibrium takes into account the fact that (over-)investing strategically leads to a better position in the third stage. This yields

$$-C_k = 1 - P'(Q)q_i \sum_{j \neq i} \frac{\partial q_j}{\partial k_i} \left[1 - \frac{\tau d}{Q^2} \sum_{i=1}^{n} e_i \right]$$

In a symmetric equilibrium welfare is given by

$$W(q,k,e) = \int_0^Q P(z)dz - nC(q,e,k) - nk - S(ne)$$

Differentiating with respect to $s = \tau, d$ we obtain

$$\frac{\partial W}{\partial s} = n\left[P(Q) - C_q\right]\frac{\partial q}{\partial s} - n\left[C_e + S'\right]\frac{\partial e}{\partial s} - n\left[C_k + 1\right]\frac{\partial k}{\partial s} = 0$$

Here we see that we cannot obtain a first-best allocation in general, for both the first and the third bracket are not automatically equal to zero. This is due to imperfect competition in the output market and strategic investment behavior in the second stage. Solving for the second-best optimal tax and refunding rate gives tedious by complicated expressions. Since these do not provide any further insight, we omit them. Nevertheless, in general the optimal refunding rate is non-zero and therefore refunding improves social welfare in this case as well.

8 Price Taking Firms

Finally, we consider the case of price taking firms. This can occur if there are many firms in the regulated industry, i.e. we have the case of perfect competition. One might argue immediately that in this case each firm's market share is small and that since – by definition of perfect competition – no firm can influence its market share, refunding taxes due to market share can have no incentive effect. Though this is true there can also be the case where domestic environmentally regulated firms are few but nevertheless those firms are price takers due to international competition, i.e. we are in a small open economy. We show, however, that even in this case refunding according to market share is not necessary. In fact, it is actively harmful. This result is quite robust. It holds for both cases, with long run abatement technologies only and with short run abatement technologies. It holds good even for the most general case of asymmetric firms. We summarize this in the following proposition.

Proposition 5

If firms behave as price-takers on the output market, the optimal tax is the Pigouvian tax, i.e. $\tau = S'(E)$, *and the optimal refunding share is* $d = 0$.

The proof is given in the appendix. To illustrate the result consider the case of long-term abatement technologies. Under perfect competition, there are no distortions due to imperfect competition. If the regulator sets the socially optimal emission tax $\tau = S'(E)$, any positive refunding would lower the incentive for investment, since firms cannot influence prices.

9 Conclusions

We have introduced refunding schemes into the design of environmental regulation. The major conclusion is that refunding according to market shares helps to improve the scope of environmental regulation if firms behave non-competitively. For long-run abatement technologies, optimal refunding schemes can achieve a first-best allocation.

Our analysis, however, can only be seen as a first step towards an integrated consideration of emission taxes and the recycling of such taxes. Numerous further issues deserve to be addressed. First, where social efficiency would require that more subsidies be paid back to the firms than emission taxes are collected, the regulator could first raise money by lump-sum taxes from industries in order to increase the amount of money which can be refunded. In this sense, the tax/tax refunding scheme could be made self-financing again if raising lump-sum taxes occurs before the regulator sets emission taxes.

Second, apart from the allocative reasons, refunding of taxes could improve the acceptance of ecological taxes by industries since the net tax burden will lower. On the other hand, firms may dislike refunding because it induces more investment incentives and higher output, and this has a detrimental effect on firms' profits. Moreover, it might be more difficult to promote collusion among firms to refrain from investment since a deviating firm will benefit more when refunding exists than when it does not. Whether such political-economic reasoning might provide a further motivation or a barrier to the use of refunding schemes is an important practical question yet to be answered. These and other questions should certainly be on the agenda for further research.

10 Appendix

Proof of Proposition 1:

Recall that $R(0) = 0$.

Consider the market share arrangements among three firms

$$\{x_1, x_2, 1 - x_1 - x_2\}$$

where x_1 and x_2 denote arbitrary market shares of the first and second firm ($0 \leq x_1 + x_2 \leq 1$). If $n > 3$, we set the market shares of the remaining firms at zero. Consider the alternative market share constellation:

$$\{0, x_1 + x_2, 1 - x_1 - x_2\}$$

Since the market share of the third firm is the same in both constellations, we obtain

$$R(x_1) + R(x_2) = R(x_1 + x_2) \tag{28}$$

We immediately obtain $R(1) = 1$ and $R(x_1) - R(x_2) = R(x_1 - x_2)$ if $x_1 \geq x_2$. From property (28) we obtain $R(kx) = kR(x)$ for any natural number k as long as $kx \leq 1$. Similarly $R(\frac{x}{n}) = \frac{1}{n}R(x)$ since $nR(\frac{x}{n}) = R(x)$ for any natural number $n \in \mathcal{N}$. Taking both properties together we obtain

$$R\left(\frac{k}{n}\right) = \frac{k}{n}, k, n \in \mathcal{N} \text{ and } k \leq n$$

Now suppose $R(\alpha) = \alpha - \Delta$ for some real number α with some $\Delta > 0$. Since any real number can be approximated arbitrarily closely by a rational number, we have $k, n \in \mathcal{N},\ k \leq n$ such that $\frac{k}{n} < \alpha$, $\alpha - \frac{k}{n} < \frac{\Delta}{2}$. Hence,

$$R\left(\alpha - \frac{k}{n}\right) = \alpha - \Delta - \frac{k}{n} < \alpha - \Delta - \alpha + \frac{\Delta}{2} = -\frac{\Delta}{2}$$

Since $\alpha - \frac{k}{n} > 0$, we obtain a contradiction since refunds are then negative. The same contradiction obtains if we assume $R(\alpha) = \alpha + \Delta$ for some $\Delta > 0$ since $R(1 - \alpha) = 1 - \alpha - \Delta$ and the same arguments as above can be applied for $1 - \alpha$. Hence, $\Delta = 0$ and $R(\alpha) = \alpha$ for all real numbers $\alpha \in [0, 1]$.

■

Proof of Lemma 1:

The last part of equation (25) follows immediately from the equilibrium condition (20). Given equation (21), we can rewrite the refunding parameter as

$$d^* = \frac{-\frac{P'(Q^*)Q^*}{(\overline{\nu}-\nu^*)}\left\{\frac{1}{n-1}+\frac{\partial q_j}{\partial \nu_j}\frac{\overline{\nu}-\nu^*}{q^*}\right\}}{S'(E)+\frac{P'(Q^*)q^*}{\overline{\nu}-\nu^*}-\frac{P'(Q^*)Q^*}{(\overline{\nu}-\nu^*)}\left\{\frac{1}{n-1}+\frac{\partial q_j}{\partial \nu_j}\frac{\overline{\nu}-\nu^*}{q^*}\right\}}$$

or simply as

$$d^* = \frac{B}{A+B}$$

Then the optimality condition (20) can be rewritten as:

$$(1-d^*)\tau^* = (1-\frac{B}{A+B})\tau^* = A$$

which implies

$$\tau^* = A + B = S'(E) - \frac{1}{n-1}\frac{P'(Q^*)q^*}{\overline{\nu}-\nu^*} - nP'(Q^*)\frac{\partial q_j}{\partial \nu_j}$$

■

Proof of Proposition 5:

Case a) Long-term abatement technology

The first-order condition of a competitive firm in the last stage is

$$p - C_i'(q_i) - (\overline{\nu}-\nu_i)\tau + \tau d\left[\frac{Q-q_i}{Q^2}\sum_{k=1}^{n}(\bar{\nu}-\nu_k)q_k + \frac{q_i}{Q}(\bar{\nu_i}-\nu_i)\right] = 0.$$

In the second stage, the competitive firm chooses ν_i such that

$$K_i'(\nu_i) = \tau q_i - d\tau\frac{q_i^2}{Q}.$$

This is so since the firm cannot influence p. Hence it cannot influence the other firms' output levels q_j. The regulator's first-order condition with respect to the tax rate is:

$$\frac{\partial W}{\partial \tau} = \sum_{i=1}^{n}\left[P(Q) - C_i'(q_i) - (\overline{\nu}_i - \nu_i)S'(E)\right]\frac{\partial q}{\partial \tau} - \sum_{i=1}^{n}\left[K_i'(\nu_i) - q_iS'(E)\right]\frac{\partial \nu_i}{\partial \tau} = 0$$

We see immediately that the case of $d = 0$ and $\tau = S'(E)$ is necessary and sufficient to implement the social optimum.

Case b) Short-term abatement technology

Now observe that the firms choose

$$\begin{aligned} p &= C_q^i(q_i, k_i, e_i) - d\frac{Q - q_i}{Q^2}\tau E \\ \tau &= -C_e^i(q_i, k_i, e_i) \\ 1 &= -C_k^i(q_i.k_i, e_i) \end{aligned} \tag{29}$$

We see that $d = 0$ leads to the first-order condition of the social optimum. Equation (29) coincides with (7). It can be easily shown that the first-best conditions (5)–(7) also hold for different firms and, hence, asymmetric allocations. Q.E.D.

■

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