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Refunding Emissions Payments

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RESOURCES FOR THE FUTURE

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Abstract

We analyze two mechanism designs for refunding emissions payments to polluting firms: output-based refunding (OB) and expenditure-based refunding (EB). In both instruments, emissions fees are returned to the polluting industry, typically making the policy more politically acceptable than a standard tax. The crucial difference between OB and EB is that the fees are refunded in proportion to output in the former but in proportion to the firms' expenditure on abatement equipment in the latter. We show theoretically that to achieve a given abatement target, the fee level in the OB design exceeds the standard tax rate, whereas the fee level in the EB design is lower. Furthermore, the use of OB and EB may lead to large differences in the distribution of costs across firms. Both designs imply a cost-ineffective provision of abatement, as firms put relatively too much effort into reducing emissions through abatement technology compared with reducing output or improving management. However, maintaining output may be seen as a political advantage by policymakers if they seek to avoid activity reduction in the regulated sector.

Key Words: refunded charge, output-based, expenditure-based, NOx, tax subsidy, policy design

JEL Classification Numbers: Q28, Q25, H23

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1. Introduction

It is well known that a uniform tax, levied on all sources of emissions, is a cost-effective instrument to reduce uniformly dispersed emissions. However, environmental taxes tend to be lower than required to correct for environmental externalities. One reason for this is concerns that high taxes reduce domestic competitiveness, leading to firm closures and job losses. Furthermore, for transboundary pollutants, such as greenhouse gases, the welfare effect of reduced domestic emissions may be partly offset by increased production and emissions abroad (carbon leakage) (see Hoel 1991). Moreover, powerful lobbies may overstate these and other arguments and thus make a cost-effective tax regime politically infeasible. All in all, the inability to levy sufficiently high environmental taxes is a problem for the design of environmental policy.

With tradable environmental permits, the quantity-based alternative to an environmental tax, the problem can be alleviated by allocating permits for free. This lowers the revenue raised in the first place, yet holds the permit price constant (to the first order), hence the abatement incentive and economic efficiency, though it creates a different political problem, that of how to allocate free permits. The same applies to the price-based equivalent of free tradable permits, giving away tradable thresholds for the emissions tax (Pezzey 2003), though this option is little known by policymakers and hence undeveloped institutionally and legally. An alternative, practical if theoretically suboptimal, way to make emissions taxes more politically feasible is to earmark the tax revenues for some environmental purpose. Some people even see the use of the tax revenues as *the* environmental purpose of the tax (see Sterner and Coria 2012). Kallbekken et al. (2011) show that recycling the revenues to more narrowly targeted groups seems to increase support for taxation. Various ways of refunding the tax revenue ease the economic burdens on

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the polluters and thus lessen political resistance to the tax. Refunding emissions can be seen as turning a tax into a fee, rebated to the polluters according to some specified rules. A tax typically implies that the revenues go toward the national budget. Revenues from a fee can be refunded or be seen as payment for a service paid to a government agency or municipality.

This paper compares two methods for refunding emissions payments:

- Refund in proportion to output, referred to as *output-based refunding* (OB).
- Refund in proportion to abatement expenditure, referred to as *expenditure-based refunding* (EB). (We also use the terms OB or EB designs, schemes, or systems).

Sweden has pioneered the use of OB for nitrogen oxides (NO_x),[1] sometimes referred to as refunded emissions payment (REP) in the literature.[2] Among the reasons for the use of OB rather than a tax was the difficulty in setting a sufficiently high price on emissions to motivate abatement when faced with a strong industrial lobby against the tax (see further Sterner and Isaksson 2006). In Sweden, fees are refunded to the polluters strictly in proportion to useful output. In the French *taxe parafiscale*, the fees (for NO_x, SO_2, HCl, and VOCs) were used generally to subsidize research and abatement (see Millock et al. 2004). The Norwegian NO_x Fund goes a step further and directly ties refunding to actual abatement costs at the firm level.[3]

EB is an interesting innovation for those situations where it is applicable and has hardly been analyzed previously.[4] The contribution of this paper is the theoretical evaluation of the

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[1] Nitrogen oxides (NO_x) are waste gases emitted from the combustion of oil, gas, and biofuel that lead to acid rain, eutrophication, and increased concentrations of ground-level ozone. Emissions have ecosystem and health effects, and Norwegian and other countries' emissions are regulated under the Gothenburg Protocol.

[2] See, e.g., Fischer (2003), Gersbach and Requate (2004), Fredriksson and Sterner (2005), Höglund Isaksson (2005), and Cato (2010). Note also that OB corresponds to output allocation or "benchmarking" in a tradable permit system (see Fischer 2001). OB generates an output subsidy and thus gives incentives for excess production. This effect is harmful in a competitive environment, but it can increase welfare under imperfect competition, where output is suboptimal (Gersbach and Requate 2004). Benchmarking in unilateral CO_2 emissions policies is motivated by its potential to reduce carbon leakage and loss of competitiveness (Edwards and Hutton 2001; Fischer and Fox 2007).

[3] For more information about the Norwegian NO_x Fund, see https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/.

[4] There is a related literature on two-part instruments. A number of papers recognize that the Pigouvian tax level may be unattainable for various reasons, and they therefore explore alternatives, such as various combinations of tax and subsidy. See, for instance, Felder and Schleiniger (2002), who analyze the trade-off between efficiency and political feasibility; and Fullerton (1997) who find that if a tax is infeasible, a satisfactory alternative may combine a subsidy to a clean substitute with a tax on output. (See also Fullerton and Mohr 2003, Bernard et al. 2007, Svendsen et al. 2001, Parry et al. 2012, Johnson 2006, or Walls and Palmer 2001 for similar points.) None of these articles,

differences in performance of the EB and OB systems, including a comparison of their qualities and properties with those of a standard environmental tax.[5] EB implies a combination of a fee on pollution and a subsidy on abatement technologies where the latter is financed by the former.[6]

By comparing the performance of the systems, we implicitly assume that all systems are applicable for the regulation in question. All systems require measurable emissions. An additional prerequisite for OB is measurable output, and EB works well only in situations where you can clearly identify and measure what is useful expenditure on "abatement technology," rather than general investment in new technology.

In section 3, we show that to achieve a certain abatement target, the fee level under OB must exceed the standard tax rate, whereas with EB it must be set lower. Both OB and EB make technical abatement relatively cheaper than abatement through output reductions, compared with a standard tax. Hence both EB and OB would be welfare inferior to the optimal standard tax system, as they lead to inferior output reductions. This comparison, however, assumes that the optimal tax is politically feasible, which is often not the case because of resistance to high taxes. We cannot, in general, say which of the systems deviate most from the cost-effective outcome. However, we identify the main driving forces for the potential discrepancy.

In the real world, the regulator's welfare function may include more than just pure economic costs, as the regulator may seek to avoid job losses or gain political support by avoiding heavy tax burdens. In the concluding remarks, we discuss welfare implications of the different systems and argue that EB and OB can be promising systems in situations where there are such political constraints on the regulator's use of taxes/subsidies and lump sum transfers.

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however, specifically looks at *refunding* of the tax per se. Millock and Nauges (2006) come the closest, analyzing the French *taxe parafiscale*, where revenue was put into a fund to which firms could apply. The refunding was not automatic, however, as in the Norwegian case.

[5] We focus on self-financed funds whose income comes exclusively from fees or designated membership contributions. An advantage of a standard tax without refunding is that it generates public revenues. In this paper, we do not take into consideration the efficiency loss due to the revenue recycling effect (Goulder et al. 1999).

[6] This is not the type of subsidy where the policymaker "buys" each unit of reduction from a baseline at a price *s* (see, e.g., Kolstad 2000, chapter 7. Such subsidies clearly imply a perverse output subsidy. Inspired by the Norwegian and French NO_x schemes, we instead model subsidies as the partial payment for the costs of particular abatement equipment.

2. A Model of Tax Compared with Refunded Fees

Consider a sector F consisting of firms indexed by $i = \{1, ..., n\}$, each producing a commodity in quantity q_i. Production causes emissions, e_i. Let e_i^0 and q_i^0 denote emissions and production in the absence of environmental policy. Each firm can reduce emissions by installing new, measurable abatement technologies or by reducing production.[7] For the sake of simplicity, we assume there is only one type of abatement technology (y) that is relevant for the sector in question. However, firms within the sector may invest in varying levels. We have

$$e_i(r_i, y_i) = e_i^0 - a_i(r_i, y_i), \tag{1}$$

where $a_i(r_i, y_i)$ is the emissions reduction (abatement) function and r_i is output reduction ($q_i^0 - q_i$).

Abatement is increasing in output reductions and abatement technology at a decreasing rate; $a'_{ir}(\cdot) > 0, a''_{irr}(\cdot) < 0$, $a'_{iy}(\cdot) > 0, a''_{iyy}(\cdot) < 0$. Furthermore, we make the following assumptions:

(A.1)The abatement function is strictly quasi-concave, and both r_i and y_i are normal input factors in the production of a_i.

(An interpretation of the abatement function is given in appendix A.)

As a starting point, we consider internal solutions for firm production decisions. Impacts on exit and entry decisions are discussed in section 3.3.

Let E stand for the sector's total emissions, assumed to be uniformly dispersed; that is:

$$E = \sum_{i \in F} e_i. \tag{2}$$

Furthermore, we define total output and total abatement as

$$Q = \sum_{i \in F} q_i, \tag{3}$$

[7] We do not address the dynamic effect or irreversibility of investments (see, e g., Coria 2009 for such models). Furthermore, in this paper, we do not delve into the incentives for technological progress created by refunding (see Sterner and Turnheim 2006). See also Jaffe et al. (2002), Löschel (2002), and Requate (2005) for surveys on technology investment incentives under various policy instruments. Note also that it may be significant *in practice* to distinguish between technologies that are easy to measure and control through simple inspection and those that are either too complex or too subtle to allow for simple monitoring.

and

$$A = \sum_{i \in F} a_i \equiv \sum_{i \in F} e_i^0 - E \equiv E^0 - E. \tag{4}$$

We assume that all market shares are so small that all firms take all prices, taxes/fees, and subsidies as given.

2.1. Standard Tax

With a standard tax, an individual firm has the following payoff:

$$\pi_i = pq_i - c_i(q_i) - my_i - t \cdot (e_i^0 - a_i(r_i, y_i)), \tag{5}$$

where *p* is the product price,[8] $c_i(q_i)$ are production costs of q_i, *t* is the tax rate on emissions, and *m* is the (annuity) cost per unit of abatement technology y_i. We apply the standard assumptions that marginal cost of production is positive and increasing: $c_i' > 0$ and $c_i'' > 0$.[9] Maximizing the profit functions yields the following first-order conditions:[10]

$$\frac{m}{a_{iy}'(r_i, y_i)} = t, \tag{6}$$

$$\frac{p - c_i'}{a_{ir}'(r_i, y_i)} = t. \tag{7}$$

The left-hand side of (6) expresses the marginal cost of reducing emissions through abatement equipment, and the left-hand side of (7) expresses the marginal cost of emissions reductions through output reductions. The intuition behind the first-order conditions is well known: the marginal cost of emissions reductions should equal the marginal benefit of emissions reduction

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8 Without loss of generality, we assume the same product price for all producers. This may be interpreted as either a situation with homogeneous goods or a situation with heterogeneous goods and a choice of units for each good making all prices identical. In the latter case, total output Q must be interpreted as the total value of production.

9 In real life, abatement technologies may also affect the cost of producing *q*. However, our simplification does not affect the main results of the paper.

10 Second-order conditions for an internal solution are given in appendix B.

(t), whether the emissions reduction occurs through abatement technology (6) or output reduction (7).

It is well known that (6) and (7) lead to a cost-effective (cost-minimizing) combination of output reduction and abatement technology deployment for all emissions levels, and an optimal emissions level allocation as long as the level of t corresponds to the true social marginal damage, often referred to as the Pigouvian tax level.

2.2. Mechanism Design for Output-Based Refunding Emissions Payments

With a standard tax, the total tax revenue, tE, is collected by the government as public revenue. A fund system implies that the tax becomes a fee and the revenue is collected by the fund. We shall focus on such cases where all the revenue is reimbursed fully to the polluters. We consider two stylized schemes for refunding emissions fees: output-based refunding (OB) and expenditure-based refunding (EB).

In an output-based refunding scheme, fees are refunded in proportion to output q_i, and the payoff to firm i is

$$\pi_i = pq_i - c_i(q_i) - my_i - t\cdot(e_i^0 - a_i(r_i, y_i)) + q_i t\frac{E}{Q}, \tag{8}$$

where t is the fee (corresponding to a standard tax) and $\frac{E}{Q}$ is the average emission. The refund per unit production is $t\frac{E}{Q}$. The budget constraint is satisfied as $\sum_{i\in F} q_i t\frac{E}{Q} = tE$. This corresponds exactly to refunding the total fee revenue tE in proportion to the firms' market shares, $\frac{q_i}{Q}$, as in the Swedish NO_x scheme.[11] As all firms' market shares are assumed to be small, they take the average emissions intensity E/Q as given,[12] although the equilibrium value of this average emissions intensity is endogenous and a function of t.

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[11] Gersbach and Requate (2004) use this setup in the competitive version of their model.

[12] See Fischer (2003) and Sterner and Isaksson (2006) for a model of an OB system where such strategic behavior is discussed. See also Gersbach and Requate (2004) for an analysis of an OB system in the context of imperfect competition in the output market and preinvestment in cleaner technology.

Assuming that the firms under OB maximize their payoffs specified in (1) and (8), the first-order conditions are as follows:[13]

$$\frac{m}{a'_{iy}(r_i, y_i)} = t\,, \tag{9}$$

$$\frac{p - c'_i}{a'_{ir}(r_i, y_i)} = t\left(1 - \frac{E}{Qa'_{ir}(r_i, y_i)}\right). \tag{10}$$

As in the standard tax system, we find that the marginal cost of emissions reductions through abatement technology should be equated with the level of the fee for all firms, equation (9). However, we see from (10) that the marginal cost of avoided emissions through output reductions is no longer equal to the level of the fee *t* but multiplied by the factor $(1 - \frac{E}{Qa'_{ir}(r_i, y_i)})$

It should also be noted that the output based refunding may leave some firms with a subsidy on production. The right hand side of (10) is negative for firms which have lower marginal emission intensity than the average emission intensity ($a'_{ir}(r_i, y_i) < \frac{E}{Q}$). Hence, some firms may actually increase their production under an output based refunding scheme compared to a situation without any environmental policy.

2.3. Expenditure-Based Refunding (EB)

With an *expenditure-based refunding scheme*, all fee revenues are refunded to the polluters in proportion to their expenditures for abatement. The payoff to a firm *i* is

$$\pi_i = pq_i - c_i(q_i) - (1-s)m \cdot y_i - t \cdot (e_i^0 - a_i(r_i, y_i))\,, \tag{11}$$

where *s* is the subsidy rate for abatement cost expenditure.

As we consider competitive firms, they all take *t* and *s* as given when making their decisions. However, it follows from the budget constraint that[14]

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[13] Second-order conditions equal the second-order conditions for the standard tax system (see appendix B). However, if we do not assume that the output share of each firm is treated as given, there is an extra factor (1 - q_i/Q) in (9) and (10). When all firms' share of total output is small, this factor is negligible (see further Fischer 2003 and Sterner and Isaksson 2006).

$$s = \frac{tE}{mY}, \tag{12}$$

where

$$Y = \sum_{i \in F} y_i. \tag{13}$$

Assuming firms maximize the payoffs specified in (1) and (11), the first-order conditions are[15]

$$\frac{(1-s)m}{a'_{iy}(r_i, y_i)} = t, \tag{14}$$

$$\frac{p - c'_i}{a'_{ir}(r_i, y_i)} = t. \tag{15}$$

By comparing (6) and (14), we see that the expressions for the marginal cost of reducing emissions through abatement technologies differ between systems. The expenditure-based refunding implies very strong incentives for abatement. Not only are emissions taxed but abatement subsidized. As s is a subsidy rate, not directly addressing any externality, we refer to the left-hand side of (6) as the marginal social cost of reducing emissions through abatement technologies, whereas the left-hand side of (14) is the marginal private cost of reducing emissions through abatement technologies in the EB scheme. It thus follows from (14) and (15) that the social marginal cost of reducing emissions through abatement expenditure exceeds the social marginal cost of reducing emissions through output reductions.

3. A Comparison of Two Mechanisms for Fefunding

In this section, we evaluate the EB and OB systems regarding cost-effectiveness, and we compare the fee levels and distribution of costs across firms. The standard tax system is used as a benchmark. However, we acknowledge that a standard tax system may, for political or practical reasons, not be achievable or preferred, as noted earlier and discussed further in section 4. We

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[14]To ensure an internal solution, we assume that the regulator always sets t such that $s < 1$. In practice, the budget of the fund might not have to balance exactly every year, and s may also be adjusted over time.

[15] Second-order conditions equal the second-order conditions for the standard tax system (see appendix B).

introduce the subscripts ST, OB and EB to refer to the outcomes of the standard tax system, the OB system, and the EB system, respectively.

3.1 Comparisons with Same Fee Level

As we saw from the previous section, the output effect of a fee under the OB system is weaker compared with a tax under a standard tax system. Under the EB system, on the other hand, the fee on pollution is complemented with a subsidy on abatement equipment, and thus makes abatement less costly. Comparing the two systems with the outcome of a tax system, we must decide whether the comparison assumes equal tax rates or equal abatement. We start with the former and show, in proposition 1, that EB gives *more* and OB gives *less* abatement than a standard Pigouvian tax of the same magnitude.

Proposition 1:

Given (A.1), we have that $a_i^{EB}(t) > a_i^{ST}(t) > a_i^{OB}(t)$ for all t.

Proof of proposition 1:
The outcome of the EB system can be mimicked by a standard tax system with prices on the abatement technology equal to $(1-s)m < m$ *, and t=* t^{ST} *. We have that* $\frac{\partial a_i}{\partial m} < 0$ *(see appendix B), such that* $a_i^{EB}(t^{ST}) > a_i^{ST}(t^{ST})$ *. The outcome of the OB system can be mimicked by a standard tax system with a tax rate of* t^{ST} *and* $p^{OB} = p + k^{OB}$*, where*

$k^{OB} = t^{ST}\frac{E^{OB}}{Q^{OB}}$ *>0. We have that* $\frac{\partial a_i}{\partial p} < 0$ *(see appendix B), such that* $a_i^{OB}(t^{ST}) < a_i^{ST}(t^{ST})$.

3.2 Comparisons with the Same Target Level of Abatement

Building on this result, we switch to a comparison between *different* levels of fees, designed to give the *same level of abatement*. Proposition 2 shows us that the tax/subsidy (EB) requires a fee that is *lower than the standard tax*, whereas output-based refunding (OB) requires a *higher* fee.

Proposition 2:

Consider a given target for abatement, and let $\overline{t}^{ST}$, $\overline{t}^{OB}$, and $\overline{t}^{EB}$ denote the tax/fee levels that ensure that the target is met in the standard tax system, the OB system, and the EB system, respectively. Given (A.1), we have $\overline{t}^{EB} < \overline{t}^{ST} < \overline{t}^{OB}$.

Proof of proposition 2:

The abatement in the standard tax system is an increasing function of the tax rate for all firms ($\frac{\partial a_i}{\partial t}>0$*, see appendix B). Furthermore, we know from proposition 1 that* $a_i^{EB}(t) > a_i^{ST}(t) > a_i^{OB}(t)$ *, for all t. Hence the* t^{OB} *that satisfies* $\sum_i a_i^{ST}(\overline{t}^{ST}) = \sum_i a_i^{OB}(t^{OB})$ *must be larger than* $\overline{t}^{ST}$*, and the* t^{EB} *that satisfies* $\sum_i a_i^{ST}(\overline{t}^{ST}) = \sum_i a_i^{EB}(t^{EB})$ *must be smaller than* $\overline{t}^{ST}$*.*

The tax rate in the EB system can be set lower for identical emissions reductions, since the tax effect is combined with a subsidy on abatement. The OB system does have a higher fee level, but thanks to the automatic refund, the average company pays nothing, and both theory and experience show that even high fee levels may be more easily acceptable under these circumstances than a tax (see Fredriksson and Sterner 2005). However, it could be costly for firms with emissions-intensive production and limited abatement options. Furthermore, output-based refunding can be controversial to operate when firms produce differentiated products and output is hard to measure.

On the other hand, we assume abatements are easy to identify and measure and that the EB system redistributes the tax revenue only in terms of subsidies to abatement technologies; thus firms that have already implemented relevant abatement technologies (or have clean production) receive no refunding of the tax revenue and could complain that they are unfairly treated. In general, the two types of funds may lead to very different distributions of costs across firms.

The magnitude of the differences in tax levels necessary to achieve a specific target depends inter alia on the firms' sensitivity to changes in variable production costs and on total emissions. For instance, consider a situation where outputs are sensitive to changes in production costs. Abatement induced by a standard tax system in that case is achieved by significant reductions in output (as a tax on emissions implies higher production costs). As discussed above, the output effect of an emissions fee under the OB system will be absent or very modest. To compensate for this, the fee level may be considerably higher than the standard tax level in order to induce sufficient investment in abatement technology. On the other hand, if output is insensitive to changes in variable production costs, the standard tax system induces abatement mostly through investment in abatement technology, and there is little difference between the fee levels of the OB system and the standard tax system.

We see from (12) that the higher the tax base (*E*), the lower the *t* needed to provide a given subsidy rate in the EB system. Hence the larger the emissions, the larger the difference in the tax rate between the standard tax system and the EB system.

Note that although the regulator, by appropriate tax/fee levels, can achieve the same total abatement level in all three systems, both the EB and OB system will lead to a combination of abatement and output reduction that is cost-ineffective compared with the ideal first best (if and when that is achievable or applicable). In that first best, a standard tax leads to a cost-minimizing distribution of output reductions, and abatement technology measures for all abatement levels. Proposition 3 formalizes this.

Proposition 3:

Given (A1), both the OB and the EB systems achieve the required abatement level by too much investment in abatement technologies and too little output reduction, compared with a standard tax system.

Proof of proposition 3: *See Appendix C.*

Although the design of the OB and EB differ substantially, they both make abatement through technology investments relatively cheaper than abatement through output reduction, compared with a standard tax. With EB, this follows from the subsidized abatement technology, whereas the OB subsidizes output.

In practice, OB and EB are likely to be used when political or practical conditions make a sufficiently high *t* in a standard tax system impossible or undesirable.[16] Thus from a political viewpoint, the relevant comparison might be between a standard tax system with a low *t*, and thus low abatement target, and OB and EB systems with a high(er) abatement target. In this case,

[16] Politicians, who make many of the relevant decisions, rarely want output reduction in any sector. On the contrary, one of the main obstacles for any environmental policy is the threat to jobs. Although a reduction in jobs in some sector might be part of an economically "optimal" strategy, it rarely goes over well with voters. Furthermore, the conditions under which the policy is optimal may not be met. This applies inter alia to cases where oligopoly exists or small, open economies where there is a threat to competitiveness through foreign competitors that do not face environmental policies.

production might still be higher under the OB and EB systems, but certainly there will be higher expenditures on abatement activities. As mentioned, higher production is often considered desirable by politicians. The investments also create employment and may speed up the development of the abatement industry through scale effects and learning by doing, possibly even creating export opportunities or other strategic advantages for domestic industry.

As we discussed in the introduction, the motivation for refunding is often to appease business and to prevent firm closure, job loss, and carbon leakage. We know that both the EB and OB refunding mechanisms lead to higher output and higher investments in abatement technologies than the standard tax system (proposition 3). The more the outcome deviates from the first best, the higher the total cost of achieving the emissions target will be. On the other hand, the establishment of a fund is typically motivated by a preference for a different combination of output reductions and abatement technology than what follows from a standard tax system. To determine the preferred fund system, it is therefore vital to know how the two different funds perform regarding output reduction versus investments in abatement technology. However, that demands an empirical investigation of the regulated sector.

Proposition 4:

Given a specific emissions target ($\bar{E}$) and (A.1), we cannot, in general, tell whether OB or EB leads to larger investment in abatement technologies and output.

Proof of proposition 4:

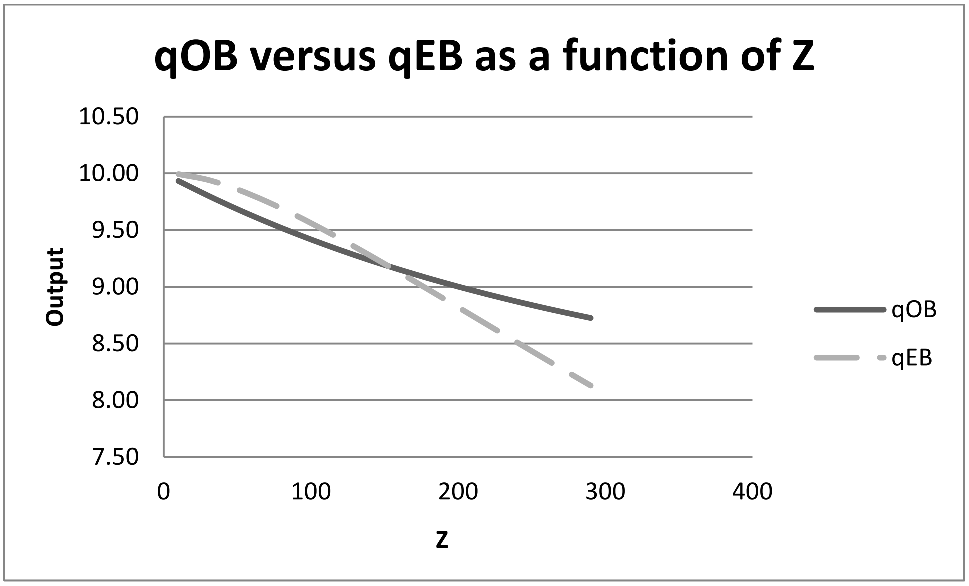
Proposition 4 can be proved by a numerical example. Assume that all n *firms are identical, and let the emissions function* (1) *be given by*

$$e_i(r_i, y_i) = e_i^0 - a_i(r_i, y_i) = Z + (\mathrm{q}_i^0 - \mathrm{r}_i)^2 - 50 \cdot \sqrt{y_i}. \qquad (16)$$

Let $c(q) = \frac{1}{2}q^2$ *, p=10, n =5, m=1, and* $\bar{E}$ *=500. For the fixed cost Z = 50 we find, from* (9), (10), (12), (14), and (15)*, that* $\mathrm{q}^{OB} = 9.68 <$ $\mathrm{q}^{EB} = 9.86$ *, whereas for Z=250,* $\mathrm{q}^{OB} = 8.84 >$ $\mathrm{q}^{EB} = 8.43$.

Figure 1 depicts the level of output under OB and EB as a function of the fixed cost *Z*, given the model specification from the proof of proposition 4. A higher *Z* means that the business-as-usual emissions increase. If we keep the emissions target constant, increasing *Z* means larger abatement. Figure 1 thus shows the impact of larger abatement requirements on output under OB and EB, all other things being equal.

Figure 1. The Outcome for Output under OB versus EB for Increasing Values of *Z*



By inserting for *s* from (12), we can write (14) as

$$a'_{y^{EB}}(r, y) = \frac{m}{t^{EB}} - \frac{\bar{E}}{Y}, \tag{17}$$

and rewriting (10) gives

$$a'_{r^{OB}}(r, y) = \frac{p - c'_{q^{OB}}}{t^{OB}} + \frac{\bar{E}}{Q} \tag{18}$$

It follows from (A.1) that an increase in abatement requirement implies that *Y* increases and *Q* decreases. For a given $\bar{E}$, this means that the last term on the right-hand side of (17) declines, whereas the last term on the right-hand side of (18) rises. Thus an increase in *Z* will ceteris paribus decrease the incentives for output reductions under OB and ceteris paribus decrease the incentives for investments in abatement technology under EB. This explains why q^{OB} can be smaller than q^{EB} for small values of *Z* and vice versa for larger values of *Z*.

3.3. Effects on Exit and Entry of Firms

In modeling the performance of the two types of funds in the previous sections, we ignored potential impacts on exit and entry. A difference between a standard tax and a refunded fee is that the former generates public revenue, whereas the fund systems are revenue neutral, as the emissions tax (fee) collected by the fund is redistributed to the firms. A standard tax may lead to a situation where some firms are no longer able to cover their total costs for any output level, and thus it is profitable for them to close down production. Compared with a standard tax system, the fund systems may prevent closures as the firms receive an income from the reimbursement of emissions taxes. Hence refunding could lead in principle to a lower degree of exit compared with a standard tax. We cannot tell in general which of the fund systems, EB or OB, would have a stronger effect in preventing closures, as the two types of funds may lead to very different distributions of costs across firms. For instance, as the EB system redistributes the tax revenue only in terms of subsidies to abatement technologies, it benefits firms with large current options for abatement investments (which often may be coupled with other investments decided by plant vintage). Firms that have low emissions levels compared with the average would, on the other hand, tend to prefer OB over EB, as they receive a higher-than-average refund of their tax payment.

We argued in section 2.2 that firms which have lower marginal emission intensity than the average emission intensity would increase their production under an OB scheme compared with a situation without any environmental policy. Thus an OB system may induce entry of new firms with low emissions per unit output, as output-based refunding in that case works as a net subsidy on production. On the other hand, an EB system might also help avoid the exit of a plant that has to undergo relatively expensive reparations or refurbishment, if the firm is able to get the investment classified as an improvement from the viewpoint of abatement and thus get a subsidy, thereby reducing the expenditure incurred. It is worth noting that the issue of monitoring and enforcement could be quite tricky in some cases, particularly if investments serve dual purposes of expansion and abatement.

4. Concluding Remarks

Our point of departure was that policymakers and indeed the public at large usually emphasize a number of aspects of environmental policy in addition to efficiency: activity reductions in local industries, possible job losses, leakage effects (polluting industries relocating to other countries), and distributional concerns loom large. Hence the environmental policy instrument preferred by most economists, the Pigouvian tax, is seldom as popular as economists think it deserves to be (though a tax combined with thresholds to lower the revenue raised rarely has been considered as a potentially more acceptable variant). We have analyzed two alternative mechanisms that imply refunding emissions payments to polluting firms: output-based refunding (OB) and expenditure-based refunding (EB). Our main findings are as follows.

Given a certain emissions target, the tax/fee level that ensures that the target is met is lower in the standard tax system than in the OB system, but it is even lower in the EB system than in the standard tax system. These differences, in turn, lead to differences in the distribution of cost across firms. Both refunding mechanisms lead to cost-ineffective combinations of abatement and output reduction, with higher output and more abatement than efficient from the viewpoint of a simple economic model. However, this effect may be seen as an advantage by policymakers if they seek to avoid activity reduction in the regulated sector.

Intuitively, one might perhaps expect that an EB system would lead to higher investment in abatement technologies than the OB systems. We found that this is not a general result. The opposite occurs if the regulated sector is sufficiently emissions insensitive and the abatement requirement is sufficiently large.

Firms that already have implemented abatement technologies before the introduction of a refund mechanism are likely to prefer an OB system, while a firm that still has profitable investment options in abatement technologies would prefer the EB system.

An important difference between the two systems is in the regulator's needs for information to regulate the systems effectively. All systems (including a regular tax) require information about firms' emissions. In addition, the OB system requires information about output, which is usually available but in many cases may be open to manipulation (such as through transfer pricing. In the Swedish NO_x policy case, the *physical* heat and energy output of boilers was chosen as a readily verifiable and relevant measure. It is not unlikely that the lack of applications in other areas is due to the difficulty of using, for instance, gross sales values as a measure. The EB system, on the other hand, demands knowledge about the firms' costs of purchasing and utilizing the abatement technology. As a result of asymmetric information between the fund's manager and the firms, the firms may gain large informational rents by overstating the cost of the abatement technology. Recall here that emissions reductions often are a consequence of different types of commercially profitable projects, such as rebuilding engines for higher efficiency. Furthermore, in order to gain informational rent, the firms may not choose the most cost-effective abatement technology project, but instead implement technologies where their private cost information advantage is the greatest.

In this paper, we have mentioned various reasons why policymakers may prefer refund systems over a standard tax system. In separate papers (Hagem et al. 2012, 2014), we have described and analyzed the empirical data on one application of the EB refunding for NO_x in Norway. Our main conclusion is that, although it is not efficient in a standard static sense, and although there are some political economy peculiarities, this still remains an interesting addition to the policy instruments available, particularly for cases when it is not possible to implement a tax that is sufficiently high (but when it is possible to identify discrete abatement investments that are desirable). An area for future research is to analyze more specifically how the optimal choice of emissions policy mechanisms depends on how the policymakers emphasize the various policy targets (e.g., emissions reductions, industries' activity level, income distribution, diffusion of abatement technologies).

We believe that economists have put insufficient interest on the use of revenues collected by environmental taxes. For businesses, NGOs, and politicians alike, this is often a very important issue. Our model has shown how refunding, either in proportion to output or to pay partially for abatement, can improve the incentives under some conditions. Experience from Sweden, Norway, and other countries has shown that this type of refunding can make the policies more politically acceptable, at least in such cases as NO_x from large industrial sources. Whether there may be a case for applications in the climate area is an interesting issue left for future research.

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Appendix A

Interpretation of function a(r,y)

Output q is given by an increasing and strictly concave production function of an input v with price p_v, and emissions are a function of output as well as technology variable y:

$$q = F(v)$$

$$e = G(q, y)$$

We assume $G_q > 0$, $G_y < 0$, and $G_{yy} > 0$. It is not obvious what the signs of G_{qq} and G_{qy} should be; we discuss this below. With this setup, the cost function $c(q)$ is $c(q) = p_v F^{-1}(q)$, and $c'' > 0$ for $F'' < 0$. Without any environmental policy, q^0 and e^0 are given by

$$c'(q^0) = p$$

$$e^0 = G(q^0, 0)$$

The abatement function $a(r, y)$ is given by

$$a(r, y) = e^0 - G(q^0 - r, y)$$

with properties

$$a_r = G_q > 0$$

$$a_y = -G_y > 0$$

$$a_{rr} = -G_{qq}$$

$$a_{yy} = -G_{yy} < 0$$

$$a_{ry} = G_{qy}$$

We assume that $G_{qq} > 0$, implying $a_{rr} < 0$. If, for example, e is proportional to v for a given y, we have $G_{qq} > 0$ due to $F'' < 0$. With these signs, $a(r, y)$ will be strictly concave (and hence strictly quasi-concave) in (r, y) provided G_{qy} is sufficiently close to zero (positive or negative). For both r and y to be normal factors, a_r / a_y must be declining in r and increasing in y. It is straightforward to see that a sufficient condition for this is that $G_{qq} > 0$ and G_{qy} are sufficiently close to zero. The condition $G_{qq} > 0$ and $|G_{qy}|$ sufficiently close to zero is hence sufficient both for the concavity of $a(r, y)$ and for r and y being normal factors.

Appendix B

In this appendix, we derive second-order conditions for global profit maximum and show how the equilibrium outcomes change with *t*, *m*, and *p* in the standard tax system.

We write the second order derivatives of the profit function as follows: $\frac{\partial \pi^i}{\partial q_i} = \pi_q^i, \frac{\partial \pi^i}{\partial y_i} = \pi_y^i, \frac{\partial^2 \pi^i}{\partial q_i \partial q_i} = \pi_{qq}^i, \frac{\partial^2 \pi^i}{\partial y_i \partial y_i} = \pi_{yy}^i, \frac{\partial^2 \pi^i}{\partial q_i \partial y_i} = \frac{\partial^2 \pi^i}{\partial y_i \partial q_i} = \pi_{qy}^i$. Given that the second-order conditions for global profit maximum are satisfied, we must have $\pi_{yy}^i = ta_{iyy}'' < 0$, $\pi_{qq}^i = -c_i'' + ta_{irr}'' < 0$, and $\pi_{yy}^i \cdot \pi_{qq}^i - (\pi_{yq}^i)^2 > 0$. $\pi_{qy}^i = -ta_{ir,y}''$.

To find how the equilibrium outcomes of the standard tax system change with *t*, *m*, and *p*, we totally differentiate the two equations (6) and (7). Given the second-order conditions and our assumption about the abatement function (see A.1), we are able to sign some of the effects:

$$\frac{\partial y_i}{\partial t} = -\frac{a_{iy}' \cdot \pi_{qq}^i + a_{ir}' \cdot \pi_{qy}^i}{D} > 0 \text{ (see below)}, \tag{19}$$

$$\frac{\partial q_i}{\partial t} = -\frac{\partial r_i}{\partial t} = \frac{a_{ir}' \cdot \pi_{yy}^i + a_{iy}' \cdot \pi_{qy}^i}{D} < 0 \text{ (see below)}, \tag{20}$$

$$\frac{\partial y_i}{\partial m} = \frac{\pi_{qq}^i}{D} < 0, \tag{21}$$

$$\frac{\partial q_i}{\partial m} = \frac{-\pi_{qy}^i}{D}, \tag{22}$$

$$\frac{\partial y_i}{\partial p} = \frac{\pi_{qy}^i}{D}, \tag{23}$$

$$\frac{\partial q_i}{\partial p} = -\frac{\partial r_i}{\partial p} = \frac{-\pi_{yy}^i}{D} > 0, \tag{24}$$

where

$$D = \pi^i_{yy} \cdot \pi^i_{qq} - (\pi^i_{yq})^2 > 0 \tag{25}$$

We find that

$$\frac{\partial a_i}{\partial t} = a'_{iy}\frac{\partial y_i}{\partial t} + a'_{ir}\frac{\partial r_i}{\partial t} = \frac{t \cdot \left[2 \cdot a'_{ir} \cdot a'_{iy} \cdot a''_{ir,y} - (a'_{iy})^2 \cdot a''_{ir,r} - (a'_{ir})^2 \cdot a''_{iy,y}\right] + \left[(a'_{iy})^2 \cdot (c''_i)\right]}{D} > 0 \tag{26}$$

Since we have assumed that $a_i(r_i, y_i)$ is strictly quasi-concave, we know that the term within the first square bracket in the numerator of (26) is positive. (The term equals the second principal minor of the bordered Hessian matrix of the abatement function, which is positive for a strictly quasi-concave function.) As (c''_i) is assumed to be positive, we have that $\frac{\partial a_i}{\partial t}$>0.

We have also assumed that r_i and y_i are normal input factors in the production of abatement. As abatement is an increasing function of *t*, we must have that $\frac{\partial y_i}{\partial t}$>0 and $\frac{\partial q_i}{\partial t} = -\frac{\partial r_i}{\partial t} < 0$.

Furthermore, we find that

$$\frac{\partial a_i}{\partial m} = \frac{a'_{ir} \cdot \frac{\partial r_i}{\partial m} + a'_{iy} \cdot \frac{\partial y_i}{\partial m}}{D} = \frac{a'_{ir} \cdot \pi^i_{qy} + a'_{iy} \cdot \pi^i_{qq}}{D} = -\frac{\partial y_i}{\partial t} < 0\,, \tag{27}$$

$$\frac{\partial a_i}{\partial p} = \frac{a'_{ir} \cdot \frac{\partial r_i}{\partial p} + a'_{iy} \cdot \frac{\partial y_i}{\partial p}}{D} = \frac{a'_{ir} \cdot \pi^i_{yy} + a'_{iy} \cdot \pi^i_{qy}}{D} = \frac{\partial q_i}{\partial t} < 0. \tag{28}$$

Appendix C

In this appendix, we prove proposition 3.

Due to the quasi-concavity of the functions a_i , y_i *and* q_i *are increasing functions of the ratio* $\frac{a'_{ir}}{a'_{iy}}$ *(for given values of* a_i *). From (6) and (7), we have* $\left(\frac{a'_{ir}}{a'_{iy}}\right)^{ST} = \frac{p - c'_i(q_i^{ST})}{m}$.

From (9) and (10), we have $\left(\frac{a'_{ir}}{a'_{iy}}\right)^{OB} = \frac{p - c'_i(q_i^{OB}) + t\frac{E}{Q}}{m}$. *From (14) and (15), we have* $\left(\frac{a'_{ir}}{a'_{iy}}\right)^{EB} = \frac{p - c'_i(q_i^{EB})}{(1-s)m}$. *Assume* $y_i^{OB} \le y_i^{ST}$ *and hence also* $q_i^{OB} \le q_i^{ST}$ *. This requires* $\left(\frac{a'_{ir}}{a'_{iy}}\right)^{OB} \le \left(\frac{a'_{ir}}{a'_{iy}}\right)^{ST}$ *, i.e.,* $\frac{p - c'_i(q_i^{OB}) + t\frac{E}{Q}}{m} \le \frac{p - c'_i(q_i^{ST})}{m}$.

Since $t\frac{E}{Q} > 0$ *and* $c''_i \ge 0$ *, this implies* $q_i^{OB} > q_i^{ST}$ *, which contradicts our initial assumption. Hence it must be true that* $y_i^{OB} > y_i^{ST}$ *and* $q_i^{OB} > q_i^{ST}$ *. Assume* $y_i^{EB} \le y_i^{ST}$ *and hence also* $q_i^{EB} \le q_i^{ST}$ *. This requires* $\left(\frac{a'_{ir}}{a'_{iy}}\right)^{EB} \le \left(\frac{a'_{ir}}{a'_{iy}}\right)^{OB}$ *, i.e.,* $\frac{p - c'_i(q_i^{EB})}{(1-s)m} \le \frac{p - c'_i(q_i^{ST})}{m}$.

Since $s > 0$ *and* $c''_i \ge 0$ *, this implies* $q_i^{EB} > q_i^{ST}$ *, which contradicts our initial assumption. Hence it must be true that* $y_i^{EB} > y_i^{ST}$ *and* $q_i^{EB} > q_i^{ST}$ *.*