Market Power and Output-Based Refunding of Environmental Policy Revenues

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Abstract

Output-based refunding of environmental policy revenues combines a tax on emissions with a subsidy to output. With imperfect competition, subsidies can discourage output underprovision. However, when market shares are significant, endogenous refunding suffers compared to a fixed subsidy. Refunding the emissions tax according to market share reduces the incentive to abate, and marginal abatement costs will not be equalized if market shares differ. In a Cournot duopoly, endogenous refunding leads to higher output, emissions, and possibly costs compared to a fixed rebate program. These results hold whether emission rates are determined simultaneously or strategically in a two-stage model.

Key Words: emissions tax, earmarking, tradable performance standards, imperfect competition, Cournot, duopoly, refunding, subsidy

JEL Classification Numbers: H21, H23, Q2

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1 Introduction

Emissions charges first emerged in environmental policy as a means to make polluters pay for the cost of remediation programs. Today, they are more often being considered for their incentive effects, as part of the pollution abatement program itself. The question then arises of what to do with the revenues, and a notable trend is to incorporate a distribution mechanism that returns them to the affected producers in proportion to their output.[1]

For example, in 1990, the Swedish government announced the implementation of an environmental charge on nitrogen oxide (NO_x) emissions beginning in 1992, its first to be based on actual emissions. The revenue is refunded to the affected plants in proportion to the amount of energy produced, so producers with a relatively high emissions rate will pay a net tax, while those with low emissions rates will receive a refund. The intent of the tax is to promote emissions reduction, while the rebate is intended to ameliorate the distributional impact of the tax, since only large producers are affected.[2] Refunding has also been credited with making a significant emissions charge palatable to industry.[3] A similar policy is the tradable performance standard, which sets average emission intensities and allocates allowances based on output. In the policy used by the United States to phase lead out of gasoline, refineries using less lead than the standard could sell these credits to others using more than average.[4] These mechanisms also are surfacing

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[1]For our semantic purposes, we will refer to the specific practice with an emissions tax as "refunding." Output-based "rebating" will represent the general practice, including refunded taxes, tradable performance standards, or output-allocated emissions permits.

[2]The rate of SEK 40 per kilo (currently about Euro 4.3 or \$2.09/lb) was set to approximate the cost of reducing (and asserted to be the marginal damage of) NO_x emissions. The charge applies only to large combustion plants, since the measurement equipment is costly. Initially, the program applied to heat and power producers with a capacity of more than 10 MW and production exceeding 50 GWh. The latter threshold was lowered to 40 GWh in 1995 and 25 GWh in 1997. The participating installations are responsible for about 5% of total Swedish NO_x emissions (SEPA, 2000).

[3]Sterner and Högland (1998).

[4]In 1982, the Environmental Protection Agency (EPA) set an inter-refinery average for lead usage among importers and refineries producing leaded gasoline.This standard was 1.10 gplg. In 1985, banking of permits was introduced as the the standard was reduced to 0.50 gplg and ultimately 0.10 gplg in 1986. The trading program ended in 1988. (EPA, 1997).

in climate policy: For example, the Netherlands has decided to use tradable performance standards for its energy-intensive sectors that are sensitive to trade.

Combining an emissions tax with an output subsidy for the participants can, in theory, be desirable in certain situations. For example, participation in the regulatory program may be incomplete, due to jurisdictional constraints—as with cross-border pollution—or technical ones—such as when monitoring systems are only cost-effective for large stationary sources. Consequently, concerns arise that imposing a cost on emissions will cause participants to lose competitiveness and emissions to leak outside the program to unregulated producers. Pre-existing labor or other taxes may be a reason: a large body of literature on tax interactions indicates that environmental policies that raise the prices of goods can exacerbate pre-existing distortions in the economy.[5] Another potential situation is imperfect competition.

It is well known that an imperfectly competitive industry has an incentive to underprovide output; taxing emissions to reduce the pollution externality then tends to exacerbate this pre-existing distortion. Tying the emissions payments to an output subsidy can mitigate this effect. However, the solution is not likely to be simple, as imperfect competition can involve many complications (see Carraro, Katsoulacos, and Xepapadeas, 1996). Cost heterogeneity can make the emissions policy a tool for shifting production between low- and high-cost firms (Simpson, 1995). Optimal tax policy may be nonlinear (McKitrick, 1999), ad valorem (Shaffer, 1995), or otherwise related to cost variance (Carraro and Soubeyran, 1995), depending on how abatement costs, production costs, and environmental feedbacks are structured. The equivalence of tax, permit, and standards policies tends to break down in multi-stage games, due to first-mover advantages or investment decisions (Copeland, 1990), or due to knowledge of the policymaker's rules, which leads to issues of enforceability and time consistency (Requate, 1993; Petrakis and Xepapadeas, 2001). Emissions policy can influence entry and market structure (Katsoulacos and Xepapadeas, 1995; Lee, 1999), or it may facilitate strategic interactions (Carlsson, 2000; Long and Soubeyran, 2000).

Earmarking environmental revenues to subsidize the regulated producers is, by definition, a second-best policy, since the rebates are not optimized but tied explicitly to emissions rents. Meanwhile, in situtations where some output subsidy is desired, the optimal level of that subsidy is tied to many other factors. For example, with imperfect competition, the elasticity of demand is important, as is cost heterogeneity, innovation opportunities, game structure, etc. With imperfect participation, the elasticities of substitution and pollution profiles of competing goods matter; a 100% rebate is only appropriate for very similar goods.

[5] See, e.g., Bovenberg and de Mooij (1994), Goulder (1995), Goulder, Parry, and Burtraw (1997), Fullerton and Metcalf (1997).

Furthermore, a rebate to the regulated sector is generally only called for when the second-best response of taxing the output of the unregulated sector is also unavailable (Bernard, Fischer and Vielle, 2001).[6]

This paper investigates the impact of market power on the incentives created by output-based rebating. We start from a point where a political decision has been made to rebate the revenues from an emissions tax;[7] thus, we abstract from the question of whether to offer a rebate and ask how it might be done. Since our focus is on the effects of rebate design, as opposed to the net effect of adopting a regulation, the fixed-subsidy case will be our baseline of comparison, rather than a no-policy or optimal policy scenario.

With perfect competition, the marginal incentives of the two schemes are identical from the point of view of the firm. In equilibrium, rebating mitigates the rise in the output price due to regulation. Correspondingly, for any emissions price, more output means greater emissions, so to achieve the same level of emissions as with no subsidy, the marginal price of emissions must rise. Thus, in the absense of other market failures, output-based rebating raises the overall cost of compliance (Fischer, 2001).

In a second-best world with imperfect competition or incomplete participation, such a diminishing of the price impact may offer some welfare improvements, as described above. However, in these situations, market shares among participants are likely to be significant. Under these conditions, output-based refunding is no longer equivalent to an emissions tax with a fixed subsidy. In the case of the output-refunded tax, large firms recognize that a share of their emissions tax payments will be returned to them. As a consequence, they have diminished incentives to reduce emissions rates and greater incentives to produce than with a fixed subsidy. Furthermore, if market shares differ, marginal abatement costs will not be equalized. As a result, abatement costs for achieving a given emissions intensity are higher, though—paradoxically—so is output. The reason is that marginal costs are still lower, due to the market share effect on the refund.

The next section develops a model for the marginal incentives of a firm facing an output-based rebate compared to an equivalent fixed subsidy, focusing on the impact of significant market shares among program participants. The third section considers the case in which firms also have significant market shares in the overall output market. A duopoly model is employed to investigate how the schemes compare, both when emissions rates and output are chosen simultaneously, and when emissions rates are established before competition in the product market. The final section offers conclusions.

[6] A caveat is the assumption of no other market failures.

[7] A distinct literature exists on the political economy of earmarking. See, for example, Wagner (1991) or Brett and Keen (2000). We remain agnostic here concerning the precise motivations for earmarking.

2 Model

Let us initially abstract from issues of competition in the output market (price effects) and concentrate on the effects of a participant having significant market share among the regulated firms (rebate effects). In many situations competition in the "rebate market" may be unrelated to competition in the product market; for example, output prices could be set on broader international markets, while only the local industry is regulated. This distinction allows us to focus on the unique effects of each rebate scheme. In the next section, we consider the joint effects of market power in both the rebate and product markets.

Let q_i and μ_i represent the output and emissions rate, respectively, of firm i. Let t be the tax price of emissions, which we assume is always fixed from the firm's viewpoint. Let s_i^x be the subsidy (rebate) per unit of output, and T_i^x represent the net tax payments for firm i. The focus, however, will be on the marginal subsidy.

2.1 Fixed Subsidy

The basic output-based rebating format is the fixed subsidy, the revenues from which equal, in equilibrium, those generated by the emissions tax. In addition to presenting a useful baseline for analysis, this case also can represent a tradable performance standard, with the caveat that participating firms must be price takers in the permit market.[8] With tradable performance standards, the average emissions rate is fixed by policy. To the extent a firm produces with emissions rates below the standard, it creates permits that it can sell; to the extent it produces with above-average emissions, it must purchase permits to cover the gap. Thus, for each unit of output, each firm gets a rebate equal in value to the emissions standard multiplied by the permit price. The subsequent equilibrium determines the price of emissions and total amount of emissions, such that the industry emissions rate average equals the performance standard.

We will refer to the fixed subsidy policy interchangeably with the tradable performance standard, denoting it with superscript S. With this policy, the firm pays tax t on emissions $\mu_i q_i$, and for each unit of output, every firm receives the same average subsidy $s_i^S = s$, which they take as given. The subsidy is set such that,

[8] This assumption may not be innocuous, but it is a useful simplification, since emissions markets raise complicated questions about the incentive and ability to exercise market power. Incentive is a function of the net permit liability, and ability must balance market power on both the supply and demand sides. See Hahn (1985).

in equilibrium, the policy is revenue neutral and total subsidies equal total emissions payments:

$$s\sum_{j=1}^{n} q_j = \sum_{j=1}^{n} t\mu_j q_j \tag{1}$$

Equivalently, we can write the equilibrium subsidy as $s = t\bar{\mu}$, where $\bar{\mu}$ represents average equilibrium emissions. The tradable performance standard functions in this manner as a fixed tax- and subsidy-rate program, as long as firms are price takers in emissions markets, since average emissions are fixed by definition.

Thus, with the fixed rebate, the firm must pay a net tax to the extent it emits more than average:

$$T_i^S(q_i, \mu_i) = t(\mu_i - \bar{\mu})q_i. \tag{2}$$

In this case, the firm's choice of emissions rate has no impact on its implicit subsidy. Thus, the marginal cost (per unit output) of an increase in the emissions rate is simply the tax:

$$\frac{\partial T_i^S(q_i, \mu_i)}{\partial \mu_i}/q_i = t. \tag{3}$$

Furthermore, since the average subsidy is fixed in the eyes of the firm, the marginal net tax on output is also constant:

$$\frac{\partial T_i^S(q_i, \mu_i)}{\partial q_i} = t(\mu_i - \bar{\mu}). \tag{4}$$

Thus, market shares do not change the marginal subsidy in a tradable performance standard program.

2.2 Refunded Tax

For expositional simplicity, we will refer to the emissions tax with endogenous output-based rebating as the "refunded tax." The policy formalized here is similar to the Swedish NO_x program. Producers face tax t on their emissions $\mu_i q_i$. Total revenue from the program is then rebated to the firms according to their shares of total output among participants, or $1/Q^T$ per unit of output, where $Q^T = \sum_{j=1}^{n} q_j$. Thus, the total net tax payments are

$$T_i^T(q_i, \mu_i) = t\mu_i q_i - \frac{\sum_{j=1}^{n} t\mu_j q_j}{\sum_{j=1}^{n} q_j} q_i \tag{5}$$

Let $\mu^T = \sum_{j=1}^{n} \mu_j q_j / \sum_{j=1}^{n} q_j$. The per-unit output subsidy subsidy can be rewritten as a per-unit subsidy of the tax rate multiplied by the average emissions rate: $s_i^T = t\mu^T$. In this formulation, the rebate appears to be the same as the performance standard subsidy. However, the key difference is that the average emissions rate—and thereby the average subsidy—is endogenous to the decisions of the firm.

First of all, a higher emissions rate for firm i not only raises the firm's tax payments per unit of output, but it also increases the average emissions rate in proportion to that firm's market share, and thus raises the firm's average subsidy:

$$\frac{\partial T_i^T(q_i, \mu_i)}{\partial \mu_i}/q_i = t\left(1 - \frac{q_i}{Q^T}\right). \tag{6}$$

The result is that, to the extent the firm's market share among the program participants is non-negligible, the rebate diminishes the effect of the tax on the emissions rate choice. Essentially, the firm knows that if it raises its emissions, it will get back some of the additional tax payments in its share of the rebated revenues. Or, if it reduces emissions, it does not get the full benefit of reduced tax payments, because its rebate also falls. In the extreme case of a monopoly, recognizing that all of its tax payments will be refunded, the firm would have no incentive to reduce emissions. More generally, larger firms will have less incentive to reduce their emissions rate than smaller firms.

Second, by expanding its output, firm i not only pays for its emissions and gets another unit of the rebate, but it also changes the average amount of that subsidy for all its inframarginal output:

$$\frac{\partial T_i^T(q_i, \mu_i)}{\partial q_i} = t(\mu_i - \mu^T)\left(1 - \frac{q_i}{Q^T}\right). \tag{7}$$

In other words, by increasing production, the firm not only raises the size of the revenue "pie" and the share it is allocated, but it also lowers the size of each "slice" by raising industry output. The net effect depends on whether the firm is an above-average or below-average emitter.

Thus, with the refunded tax, output share has two effects: First, it tempers the effect of the emissions tax. Second, it also tempers the effect of the average output subsidy. Consequently, firms of different sizes face different effective tax and subsidy rates, and one of the advantages of market-based environmental policy—marginal cost equalization—will be compromised. Finally, we observe that as the number of firms grows very large ($q_i/Q^T \to 0, \forall i$), the refunded tax becomes identical to the tradable performance standard.

3 Cournot Competition

3.1 Simultaneous Duopoly Game

In this section, we explicitly model product markets and investigate the interactions between imperfect competition, output-based rebating, and cost heterogeneity. To this end, we employ a simple Cournot duopoly with linear demand and cost functions. Given that output-based rebating, by definition, must be implemented across identical or sufficiently similar products, Cournot competition seems like a reasonable choice to characterize the likely form of imperfect competition. For example, electricity generators provide an identical good and make quantity decisions regarding their production capacity. Of course, one could envision output-based rebating applied to differentiated products—tradable fuel economy standards for cars, for example—for which Bertrand competition might be more appropriate. However, for now, we focus on output decisions and Cournot competition.

Let us first present the general model, to which we will apply the specific policies. Production costs are assumed to take the form $C(q_i, \mu_i) = (c_i + a(\mu_i))q_i$, which exhibits constant marginal production costs that vary with the emissions rate. Let $a(\mu_i)$ be a decreasing function of the emissions rate, with $a'(\mu_i) < 0$, $a''(\mu_i) > 0$, and $a'(\mu_i) = 0$ for some finite μ^0 where $a(\mu^0) = 0$.

According to Cournot competition, firm i takes its rival's production as given. Let h_i represent firm i's market share: $h_i = q_i/Q$, where $Q = q_i + q_j$; consequently, $\partial h_i/\partial q_i = (1 - h_i)/Q$. We will further assume that the demand function take the following form: $P(Q) = y - bQ$. By imposing on them these functional forms in a duopoly model, we can consider the equilibrium effects of the different refunding policies. In examples with cost heterogeneity, we will generally consider firm 1 to be the relatively high-cost firm, or $c_1 \geq c_2$. In a general form, firm i maximizes profits

$$\pi_i = (y - b(q_i + q_{-i}) - c_i - a(\mu_i))\, q_i - T^x(q_i, \mu_i; q_{-i}, \mu_{-i}), \tag{8}$$

taking its rival's output and emissions as given. Maximizing with respect to its emissions rate, we see that marginal abatement costs equal the price of emissions, net of any change in the subsidy:

$$\frac{\partial \pi_i}{\partial \mu_i} = 0 : \quad -a(\mu_i) = \frac{\partial T_i^x}{\partial \mu_i}. \tag{9}$$

Maximizing with respect to output,

$$\frac{\partial \pi_i}{\partial q_i} = 0: \qquad y - b(q_i + Q) = \psi_i^x, \tag{10}$$

where ψ_i^x represents the full marginal cost to the firm (inclusive of the relevant emissions price and subsidy) of an additional unit of output under regime x:

$$= c_i + a(\mu_i) + \frac{\partial T_i^x}{\partial q_i} \tag{11}$$

Thus, (10) states that the firm's profits are maximized when marginal revenues equal these full marginal costs.

Cournot competition with linear demand offers the straightforward result that total output is a function of total marginal costs, and market share is a function of relative marginal costs. Adding the conditions for each firm, we can solve for Q^x:

$$Q^x = \frac{1}{3b}(2y - \psi_1^x - \psi_2^x). \tag{12}$$

Substituting back into each firm's first-order condition and solving for output, we get

$$q_i^x = \frac{1}{3b}(y - 2\psi_1^x + \psi_2^x). \tag{13}$$

Taking the ratio for the market share of firm 1 in regime x, we see that it declines with the difference in marginal costs compared to the rival:

$$h_1^x = \frac{q_i^x}{Q^x} = \frac{1}{2} - \frac{3(\psi_1^x - \psi_2^x)}{2y - \psi_1^x - \psi_2^x}. \tag{14}$$

Using this model structure, we now compare the two policy regimes.

3.1.1 Fixed Subsidy

The fixed tax-subsidy case is again our reference baseline. Substituting (3) into the first-order condition for the emissions rate (9), we see that each firm equalizes marginal abatement costs to the tax rate:

$$-a'(\mu_i) = t. \tag{15}$$

With the fixed subsidy, the requirement of revenue neutrality is equivalent to actual average emissions being equal to the standard. In the duopoly equilibrium, $\bar{\mu} = h_1\mu_1 + h_2\mu_2$. With identical abatement-related costs, given the same tax, each firm will choose the same emissions rate, or $\mu_i = \bar{\mu}$. Thus, our reference tax rate can also be defined as the emissions price that achieves the performance standard, or $t = a'(\bar{\mu})$.

From the previous analysis, we know that both firms get the same marginal output subsidy, $t\bar{\mu}$. Full marginal costs for firm i then, in equilibrium, is

$$\psi_i^S = c_i + a(\mu_i) + t(\mu_i - \mu_j)(1 - h_i) \tag{16}$$

With identical abatement-related costs, given the same tax, each firm will choose the same emissions rate, or $\mu_i = \bar{\mu}$, and $\psi_i^S = c_i + a(\bar{\mu})$. Substituting (16) into (12) gives us the equilibrium Q^S:

$$Q^S = \frac{2y - c_1 - c_2 - a(\mu_1) - a(\mu_2) + t(\mu_1 - \mu_2)(h_1 - h_2)}{3b} = \frac{2y - c_1 - c_2 - 2a(\bar{\mu})}{3b} \tag{17}$$

Substituting into (14), we see that that firm 1 gets less (more) than half of the market if its marginal costs are more (less) than firm 2's:

$$h_1^S = \frac{1}{2} - \frac{3(c_1 - c_2)}{2Q^S}.$$

Since both firms get the same rebate, the subsidy does not affect market share.

3.1.2 Refunded Tax

Section 2.2 showed that when firms are heterogeneous, the output-refunded tax discourages large firms from abating emissions and subsidizes high emitters to a greater extent. In a system of Cournot competition, this scheme leads higher emissions and greater output compared to a fixed subsidy.

Substituting (6) into the first-order condition for the emissions rate (9), we see that the bigger i's market share, the higher its emissions rate:

$$-a'(\mu_i) = t(1 - h_i). \tag{18}$$

Thus, both firms emit more than with the fixed rebate, and a lower-cost firm with higher market share will emit at a higher rate.

Meanwhile, when the firm simultaneously chooses its output quantity, its full marginal costs are

$$\psi_i^T = c_i + a(\mu_i) + t(\mu_i - \mu_j)(1 - h_i)^2 \tag{19}$$

Given any emissions rate, marginal costs are lower here by $th_i(1 - h_i)(\mu_i - \mu_j)$ compared to the fixed-subsidy policy. However, from (18) we know that emissions rates will differ with market shares. Now, the larger firm will emit more than the smaller, so the larger firm will pay a positive net tax, while the smaller firm receives a net subsidy. On the other hand, the larger firm will also have lower abatement-related costs than the smaller one.

Substituting (19) into (12) we get an expression for industry output Q^T:

$$Q^T = \frac{2y - c_1 - c_2 - a(\mu_1) - a(\mu_2) + t(\mu_1 - \mu_2)(h_1 - h_2)}{3b}. \tag{20}$$

Initially, this expression looks identical to that from the fixed-subsidy world; however, the underlying variables are different. First, from (18) we see that emissions rates diverge when production-related costs are heterogeneous, even if abatement-related costs are identical, due to the market-share effect. Second, we will show that total marginal costs are lower compared either to the fixed-rebate case with either an equivalent tax or an equivalent emissions intensity standard. This implies that in both cases, the refunded tax leads to higher output and higher total emissions.

To explore these results, let us state the following lemmata, which derive from the first-order conditions for profit maximization with respect to the emissions rate for each policy:

Lemma 1 *If* $\mu_i^T = \arg\max\{\pi_i^T(\mu_i, q_i)\}$, *then for any* $\mu \neq \mu_i^T$, $a(\mu_i^T) + t\mu_i^T(1 - h_i^T) \leq a(\mu) + t\mu(1 - h_i)$.

Lemma 2 *If* $\mu_i^S = \arg\max\{\pi_i^S(\mu_i, q_i)\}$, *then for any* $\mu \neq \mu_i^S$, $a(\mu_i^S) + t\mu_i^S \leq a(\mu) + t\mu$.

Let us compare two tax-rebate policies to the tradable performance standard benchmark: 1) a refunded tax with the same tax rate, and 2) a refunded tax targeting the same average emissions standard. First, with a tax rate identical to that in the fixed-rebate scheme, output-based rebating implies emissions rates that are higher, due to the market-share effect. As a result, we can formulate two propositions.

Proposition 3 *The marginal cost for each firm is strictly lower when a given tax rate is refunded based on output than by a fixed, revenue-neutral subsidy* ($\psi_i^T < \psi_i^S$).

Proof. Since abatement-related cost functions are identical, $\mu_1^S = \mu_2^S$. From (18) we know that, given any t, $\mu_i^T > \mu_i^S$, which implies $a(\mu_i^S) > a(\mu_i^T)$. Furthermore, if $h_1^T < h_2^T$, then $\mu_1^T > \mu_2^T$. Designating $h_1^T < 1/2$, then $\psi_1^S = c_1 + a(\mu_1^S) > c_1 + a(\mu_1^T) + t(\mu_1^T - \mu_2^T)(1 - h_1^T)^2 = \psi_1^T$, since $a(\mu_1^T) < a(\mu_2^S)$ and $\mu_1^T < \mu_2^T$, and $\psi_2^S = c_2 + a(\mu_2^S) > c_2 + a(\mu_2^T) + t(\mu_2^T - \mu_2^S)(h_1^T) > c_2 + a(\mu_2^T) + t(\mu_2^T - \mu_1^T)(h_1^T)^2 = \psi_2^T$, by Lemma 1, and since $\mu_1^T > \mu_1^S = \mu_2^S$, $\mu_1^T < \mu_2^T$ and $h_1^T < 1$. ∎

Proposition 4 *For an equivalent tax rate, a refunded tax raises output and emissions compared to a fixed subsidy.*

Proof. From (12) we see that Q increases when $(\psi_1 + \psi_2)$ decreases. Thus, from Proposition 3, $\psi_1^S + \psi_2^S > \psi_1^T + \psi_2^T$, implying $Q^T > Q^S$. Since $\mu_i^T > \mu_i^S = \bar{\mu}$ from (18), $\mu^T = h_1^T \mu_1^T + h_2^T \mu_2^T > \bar{\mu}$. Thus, $\mu^T Q^T > \bar{\mu} Q^S$. ∎

Both individual and average emissions are higher compared to the fixed subsidy, due to the weaker incentive to abate with the refunded tax. Higher emissions rates mean higher tax payments, but also higher subsidies and lower abatement-related costs, and the latter effects dominate. The overall effect is thus to raise total output compared to the fixed subsidy. Since both output and emissions rates are higher, total emissions must then be higher. A corollary to Proposition 4 follows.

Corollary 5 *To achieve the same emissions intensity, a refunded tax must be higher than an emissions tax with a fixed subsidy.*

Suppose instead the output-rebated tax achieves the same emissions standard as the tradable performance standard. In formal terms, let $\bar{t}$ be the set such that $h_1^T \mu_1^T + h_2^T \mu_2^T = \bar{\mu}$. Since we know that average emissions are higher with output-based refunding of an equal tax rate, then it must be that $\bar{t} > t$. In the simplest case of identical firms, it is easy to see from (18) that $\bar{t} = 2t$—in other words, doubling the emissions tax eliminates the market share effect in the duopoly. However, with heterogeneous firms, the refunded tax cannot achieve results identical to a fixed subsidy.

Proposition 6 *For an equivalent average emissions standard, a refunded tax raises output and emissions compared to a fixed rebate rate.*

Proof. From Lemma 1, $a(\mu_i^T) + \bar{t}\mu_i^T(1 - h_i^T) \leq a(\bar{\mu}) + \bar{t}\bar{\mu}(1 - h_i)$. Then

$$\begin{aligned}
\psi_1^T + \psi_2^T &= c_1 + c_2 + a(\mu_1^T) + a(\mu_2^T) + \bar{t}(\mu_1^T - \mu_2^T)(1 - 2h_1^T) \\
&\leq c_1 + c_2 + 2a(\bar{\mu}) + \bar{t}(\bar{\mu} - h_1\mu_1^T - (1 - h_1)\mu_2^T) \\
&= c_1 + c_2 + 2a(\bar{\mu}) = \psi_1^S + \psi_2^S
\end{aligned}$$

Since total marginal costs are lower with the refunded tax, $Q^T > Q^S$. Since the average emissions rate $\mu^T = \bar{\mu}$ by definition in this problem, $\mu^T Q^T > \bar{\mu} Q^S$. ■

Corollary 7 *To achieve the same total amount of emissions, a refunded tax must target a lower emissions rate than the tradable performance standard.*

Since output is higher for the refunded tax than a comparable tradable performance standard, the average emissions rate must be lower to bring total emissions to the same level. These results are strict for the Cournot duopoly when costs are heterogeneous. Furthermore, in this case we can also show that for the same standard of emissions intensity, average abatement-related costs ($h_1 a(\mu_1) + h_2 a(\mu_2)$) are higher with endogenous refunding.

Proposition 8 *For an equivalent average emissions standard, a refunded tax raises average abatement-related costs compared to a fixed subsidy.*

Proof. From Lemma 2, if $\mu_i^S = \bar{\mu}$, $a(\bar{\mu}) + t\bar{\mu} \leq a(\mu_i^T) + t\mu_i^T$. Thus, $h_1^T a(\mu_1^T) + h_2^T a(\mu_2^T) > h_1^T(a(\bar{\mu}) + t\bar{\mu} - t\mu_i^T) + h_2^T(a(\bar{\mu}) + t\bar{\mu} - t\mu_2^T) = h_1^T a(\bar{\mu}) + h_2^T a(\bar{\mu}) = a(\bar{\mu}) = h_1^S a(\bar{\mu}) + h_2^S a(\bar{\mu})$. ■

The effect on overall production and abatement costs will depend on how market shares respond, and cost heterogeneity has mixed effects in this case. If $c_1 > c_2$, then the high-cost firm has lower market share ($h_1^T < 1/2$), and thereby from (18) a lower emissions rate $\mu_1^T < \mu_2^T$. The net effect on the market share of the high-cost, lower-emissions firm is

$$h_1^T = \frac{1}{2} - \frac{3(c_1 - c_2 + A)}{Q^T}, \tag{21}$$

where $A = a(\mu_1^T) - a(\mu_2^T) + t(\mu_1^T - \mu^T)(1 - h_1^T) - t(\mu_2^T - \mu^T)h_1^T$, with $\mu^T = h_1^T\mu_1^T + h_2^T\mu_2^T$ denoting average emissions with the refunded tax. The question is whether the difference in abatement-related costs outweighs the difference in net marginal tax payments and the increase in output.

Proposition 9 *For an equivalent average emissions standard, a refunded tax increases marginal cost disparity compared to a fixed subsidy.*

Proof. $\psi_1^T - \psi_2^T > \psi_1^S - \psi_2^S$ if $A > 0$. From Lemma 2, $a(\mu_1^T) > a(\bar{\mu}) + t(\bar{\mu} - \mu_1^T)$. From Lemma 1, $a(\mu_2^T) < a(\bar{\mu}) + t(\bar{\mu} - \mu_2^T)h_1$. Then $A > a(\bar{\mu}) + t(\bar{\mu} - \mu_1^T) - a(\bar{\mu}) + t(\bar{\mu} - \mu_2^T)h_1 + t\mu_1^T(1 - h_1^T) - t\mu_2^T h_1^T - t\mu^T(1 - 2h_1^T) = t((\bar{\mu} - \mu^T)(1 - h_1) + (\mu^T - \mu_1^T))$. When $\bar{\mu} = \mu^T$, it follows that $A > 0$, since $\mu_1^T < \mu^T$. ■

However, in terms of the market share differential, it is unclear whether this additional cost disparity is sufficient to outweigh the effects of greater output. The ultimate result depends on demand parameters, as well as abatement costs. The above formulation of A also reveals that as μ^T increases, the cost disparity shrinks. Thus, the high-cost firm is more likely to gain market share under the refunded tax when the tax rather than the standard is held equal, since marginal costs and their difference are smaller and the output effect is stronger.

In terms of overall average costs, if $h_1^T > h_1^S$, then average production-related costs are necessarily higher, as well as abatement-related costs. If $h_1^T < h_1^S$, then at least some of the increase in abatement-related costs is offset by shifting production to the lower-cost producer. Since both policies are revenue neutral, the net tax payments do not affect average costs directly.

It may be paradoxical that output is higher when average production costs may be higher. The key point is that marginal costs (inclusive of the tax incentives) are lower, although the costs of meeting the standard are not minimized. The increase in costs as well as emissions then exacerbates the efficiency loss of output-based refunding relative to a fixed subsidy.

3.2 Two-Stage Game

Suppose the emissions rate and output decisions are not made simultaneously, but rather the emissions rate is chosen before output. In this case, each firm knows its emissions rate choice will help determine the subsequent output and market-share equilibrium. Do the different incentives with respect to output then change the emissions rate decision?

Consider a Cournot duopoly playing a two-stage game in which firms simultaneously choose emissions rates and then simultaneously choose output. In general, with two-stage Cournot competition, players attempt to raise their rival's marginal cost and lower their own, in order to have a market-share advantage.[9] Here, the strategy is not only in terms of abatement costs, but also the tax and subsidy. We consider the problem from the point of view of firm 1, recognizing that 2's problem is a mirror image. The distinction in this game is that the implicit subsidy is now not only a function of the firm's own emissions rate and output, but the competitor's equilibrium output, given the competitor's chosen emissions rate.

In the second stage, firms choose output quantities given their emissions rates and their competitor's output, with the first-order conditions being the same as in the previous section for the simultaneous game. In the first stage, however, each firm chooses its emissions rates, given its competitor's rate, knowing how that will affect the subsequent output equilibrium:

$$\frac{\partial \pi_1^{2S}}{\partial \mu_1}/q_1 = -a'(\mu_1) - \frac{\partial T_1}{\partial \mu_1} + \frac{\partial \pi_1}{\partial q_2}\frac{dq_2}{d\mu_1}\frac{1}{q_1} = 0 \tag{22}$$

By the second-stage first-order conditions, $\partial \pi_1/\partial q_1 = 0$; therefore, the impact of small changes in the emissions rate on the firm's own output does not affect profits. However, changes in the competitor's output do. Profit is decreasing in the competitor's output ($\partial \pi_1/\partial q_2 < 0$) by reducing prices and average subsidies; the competitor's output is decreasing in the firm 1's emissions rate to the extent it increases firm 1's output or decreases firm 2's subsidy.

3.2.1 Fixed Subsidy

With the fixed rebate rate or tradable performance standard, we continue to assume that the firm takes the marginal subsidy as invariant to its own behavior. Thus, no permit price change is expected, nor a policymaker response.

Using our linear demand example, solve from (13) and (16) for firm 2's output in the second stage:

$$q_2 = \frac{1}{3b}\left(y - 2c_2 - 2a_2(\mu_2) + c_1 + a(\mu_1) - t(2\mu_2 - \mu_1 - \bar{\mu})\right). \tag{23}$$

[9] Shaffer and Salant (1998) show that, in a game of marginal-cost reducing investments among Cournot players, the symmetric noncooperative equilibrium represents a local minimum. Each firm overinvests in order to achieve a marginal cost advantage in the subsequent output game. This result would hold for emissions abatement if high fixed-cost investments were chosen consistently over high marginal-cost abatement techniques, when a mix would be preferred. However, we consider only marginal-cost technologies in this case.

From (23), (8), and (2) we derive

$$\frac{dq_2}{d\mu_1} = \frac{a'(\mu_1) + t}{3b}; \qquad \frac{\partial \pi_1}{\partial q_2} = -bq_1. \tag{24}$$

Substituting into (22), we get

$$-a'(\mu_1) = t + \frac{a'(\mu_1) + t}{3}, \tag{25}$$

which can only hold when $-a'(\mu_1^S) = t$ in the two-stage game. Thus, if the subsidy is fixed (or the firms are price-takers in the tradable performance standard market and the average emissions rate constraint binds in equilibrium), the two-stage game produces the same results as the simultaneous game. Essentially, each rival wants to commit to low marginal costs to maximize market share, and efficient abatement levels achieve the lowest marginal costs under this policy.

3.2.2 Refunded Tax

With the refunded tax, the impact of market shares on marginal subsidies and marginal abatement incentives leads to somewhat different (and more complicated) outcomes in the two-stage framework. From (13) and (19), we get

$$q_2 = \frac{1}{3b}\left(y - 2c_2 - 2a(\mu_2) + c_1 + a(\mu_1) + t(\mu_1 - \mu_2)(1 - 2h_1 + 3h_1^2)\right) \tag{26}$$

In the first stage, firm 1 chooses its emissions rate, recognizing that $(\partial T_i/\partial \mu_i)/q_i = t(1 - h_i)$. From (22) we have

$$-a'(\mu_1) = t(1 - h_1) - \frac{\partial \pi_1}{\partial q_2}\frac{dq_2}{d\mu_1}\frac{1}{q_1} \tag{27}$$

Deriving the components of the latter term, using (23), (8), and (5),

$$\frac{dq_2}{d\mu_1} = \frac{1}{3b}\left(a'(\mu_1) + t(1 - 2h_1 + 3h_1^2) + t(\mu_1 - \mu_2)(6h_1 - 2)\frac{dh_1}{d\mu_1}\right) \tag{28}$$

$$\frac{\partial \pi_1}{\partial q_2} = -bq_1 - th_1^2(\mu_1 - \mu_2) \tag{29}$$

Here it is evident that emissions rate choice has complicated strategic effects, due to the effect on tax payments and shares of the revenues. Since market share affects the expected subsidy and the rival's output in a way that is not proportional to the direct effect on costs, the strategy for choosing the emissions rate is different in the two-stage game.

To simplify this problem, let us restrict the analysis to identical firms, where $c_1 = c_2 = 0$. In the symmetric equilibrium, $\mu_1 = \mu_2$, and $h_1 = 1/2$. Substituting into (27) and solving for the marginal cost of abatement per unit, we see that marginal abatement costs are somewhat higher than in the simultaneous Cournot game, in which $dq_2/d\mu_1 = 0$ and $-a'(\mu^T) = t/2$. :

$$-a'(\mu^{T_{2S}}) = \frac{9}{16}t > \frac{1}{2}t.$$

Emission rates will then be lower, since each firm competes for a higher net subsidy from the program to maintain and enhance its market share. This strategic effect mitigates, to some extent, the effect of the refunded tax to raise emissions rates compared to an equivalent emissions tax with a fixed subsidy.

We also see from (28) and (29) that cost heterogeneity may have important effects. When costs are not symmetric, the analysis becomes complicated, and the results are likely to be ambiguous. Whether or not the firm increases or decreases abatement relative to the simultaneous game depends on the sign of the marginal profits from influencing the rival. This has the effect of creating a wedge between $-a'(\mu_1)$ and $t(1 - h_1)$. Since profits always fall as the rival's production increases ($\partial\pi_1/\partial q_2 < 0$), the sign of this wedge depends on $dq_2/d\mu_1$. Let $\Delta = -a'(\mu_1) - t(1 - h_1)$. Substituting into (27) and solving for Δ, we see the importance of market share in determining the sign:

$$\Delta = \frac{-\partial\pi_1/\partial q_2}{-\partial\pi_1/\partial q_2 + 3bq_1}\left[t(3h_1 - 1)\left(h_1 + 2t(\mu_1 - \mu_2)\frac{dh_1}{d\mu_1}\right)\right] \tag{30}$$

The first term in the brackets $(3h_1 - 1)$ is positive for market shares $>$1/3 and negative for market shares $<$1/3. In the second term, $h_1 > 0$ while $\mu_1 - \mu_2 < 0$, and the sign of $dh_1/d\mu_1$ tends to be positive for the smaller firm.[10] Assuming the net effect is positive, all else equal, a very small player would have less incentive to abate in the two-stage game, while a larger player would abate more than in the simultaneous game and more than if its rival were more equal. Of course, the direct effect of falling market share is to increase abatement incentives, so a smaller firm 1 would still have a lower emissions rate than larger firm 2, other things equal. So as long as the impact of changing market share on the emissions rate is a second-order

[10]Evaluated at some $h_1 < 1/2$, and using (18), from (20) $\partial Q^T/\partial\mu_1 = h_1 t > 0$, and $\partial A/\partial\mu_1 = h_1(2h_1 - 1)t < 0$. Thus, from (21), raising μ_1 should bring firm 1's market share closer to 1/2.

effect, increasing cost heterogeneity means that in the two-stage game, the dampening effect of market share is somewhat mitigated for sufficiently large firms, while for smaller firms it is exacerbated, resulting in a smaller differential between emissions rates.

4 Conclusion

The intent of rebating environmental policy revenues is to mitigate the cost burden on participants. The reasons may be to maintain equity, to prevent production from shifting to unregulated sectors, or plainly to garner political support of regulation. Output-based rebating is attracting attention because it provides a seemingly fair rule of distribution of the policy rents and because it allows the allocations to respond automatically to changes in market conditions over time. Furthermore, the subsidy to output may help counteract leakage due to incompete regulatory coverage or counteract the effects of imperfectly competitive markets. In essence, two problems exist in the latter case—insufficient output due to imperfect competition and overproduction of emissions due to the externality. Thus, two policy tools are needed to address them both, one to internalize the externality and one to encourage output.

However, output-based rebating can cause some problems. First, the effective subsidy from an earmarking program is unlikely to be the optimal one. The marginal rebate is tied to the value of emissions in the program, rather than the degree of output underprovision or leakage. It can be greater or less than optimal, depending on the relative costs of emissions and demand elasticities. In particular if it is greater, the wrong subsidy can be worse than no subsidy. Thus, a tailored fixed subsidy implemented with the environmental policy may be preferred to full earmarking of the implicit (or explicit) revenues.

Second, combining an emissions tax with an endogenously determined rebate can lead to different effective tax and/or subsidy rates when market shares among program participants are significant. These additional distortions occur because firms then know that part of any emissions rents they create will be returned to them with their refund. Since changing emissions changes the tax revenues that will be refunded, the expectation of a large rebate share reduces the incentive to reduce emissions. Thus, the refunded tax has the effect of increasing both emissions and output, relative to an equivalent tax with a fixed subsidy. This result still holds when emissions rates are chosen before output, although strategic effects may then induce more abatement than in a simultaneous game.

Furthermore, when market shares differ, marginal abatement cost equalization is also sacrificed. In this case, when adjusting the tax rate to target the same standard, the output-refunded tax raises abatement-related costs. However, it also raises output and emissions relative to a tradable performance standard. For these reasons, a fixed subsidy is again preferred to endogenous refunding when market shares among participants are significant.

In the case of the Swedish NO_x charge, this concern should not weigh heavily. Although participants include large producers in industries that may not be perfectly competitive, no producer has more than roughly 2% of the rebate market, since the tax-refund program includes several industries.[11] Thus, by using a broad program, they avoid the market-share issues that could arise with sector-specific programs. In a multi-industry program, however, the efficiency of the subsidy may vary, since each industry may face different demand structures and have different opportunities to seek energy outside the program. While the subsidy may prevent participants from seeking energy from smaller, more polluting sources that are exempt, it also confers no incentives to switch to non-polluting generators like wind or hydropower, which are excluded as well. In the Swedish example, the subsidy amounts to 10% or less of the variable costs of generation.[12]

Many of the results with this model should also extend to Bertrand competition, as in the case of differentiated products that are imperfect substitutes, although pricing and welfare would differ.[13] The common points are that prices are an increasing function of marginal costs, output is a decreasing function of marginal costs, and market shares are a function of the cost differential. Since the results here are driven by the difference in full marginal costs under the two regimes, the policy comparison will be similar with different demand and competitive structures.[14] Other interesting extensions involve the dynamic game. The fixed subsidy may not seem so fixed over time when the target of revenue neutrality is known, or the price of tradable performance standards is endogenous. Time consistency may also be an issue for the policy maker; while we have abstracted from the exact goals of the environmental policy to focus on the rules, how those rules are set may also have strategic implications.

Obviously, efficient, revenue-raising policies and independent tools for correcting market distortions are generally preferred to constrained policies. However, political realities must be taken into account, and

[11] Participating industries are food, wood, pulp and paper, metals, chemicals, combined heat and power, and waste incineration. Approximately 250 plants are involved. (SEPA, 2000.)

[12] For example, the refund is about SEK 10 per MWh (SEPA, 2000), while variable costs for generation in combined heat and power plants range from about SEK 100-200 per MWh (SEA, 2002).

[13] Although differentiation cannot be so strong as to make output calculation incomparable, some form of imperfect substitution is necessary to allow for heterogeneous firms.

[14] A caveat may be that the number of firms is fixed; entry has not yet been considered.

market-based environmental policies with output-based refunding may still dominate command-and-control policies and no policy or no subsidy. Given the potential for quite different outcomes, more research is required to assess the relative size of the efficiency losses from using refunding mechanisms in policies to address environmental externalities in highly concentrated industries.

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