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Résumé:

Abstract:

This paper re-considers environmental subsidies in the context where polluting firms procure their abatement goods and services from a specialized oligopoly. To maximize social welfare, the regulator must then simultaneously alleviate two distortions: one that comes from pollution and the other that is due to the environment firms' market power. We find that combining an emission tax to a subsidy to polluters cannot lead to first-best, while the opposite conclusion holds if the subsidy is granted instead to environment firms. When public transfers are themselves subject to distortions, however, welfare may be higher if only an emission tax is used.

Mots clés : Subvention environnementale, Taxe pigouvienne, Eco-industrie

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Classification JEL: H23, L13, Q58

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Environmental Subsidies and the Eco-Industry*

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This paper re-considers environmental subsidies in a context where polluting firms procure their abatement goods and services from a specialized oligopoly. To maximize social welfare, the regulator must then simultaneously alleviate two distortions: one that comes from pollution and the other which is due to the environment firms' market power. We find that combining an emission tax with a subsidy to polluters cannot lead to first-best, while the opposite conclusion holds if the subsidy is granted instead to environment firms. When public transfers are themselves subject to distortions, however, welfare may be higher if only an emission tax is used.

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1. Introduction

Subsidies have long been proposed as a public policy measure to deal with environmental externalities (Pigou 1920, Lerner 1972). Critiques argue they contradict the 'Polluter-pays Principle', are less efficient than taxes (Fredriksson 1998), and may even encourage the depletion of environmental resources (Kohn 1992, Barde and Honkatukia 2004), while supporters claim they fulfill redistribution objectives (Fredriksson 1998), might accelerate the transfer of cleaner technologies (Stranlund 1997), and might also enhance social welfare when combined with taxes (Kohn 1991, Conrad 1993, Fullerton and Mohr 2002).

All the analyses so far have assumed that polluters know and pay exactly the cost of reducing their polluting emissions. Pollution abatement good and services, however, are now largely being delivered by a specialized environment industry. In 2005, this industry totalled earnings of \$653 billions, and this figure has been projected to reach \$780 billions by 2010.[1] Several studies reveal, then, that the various segments of the eco-industry are imperfectly competitive (Karliner 1994, Barton 1997, Davies 2002), which entails that environment firms will usually charge a markup to their polluting clients.

The recent papers that took these stylized facts into account now suggest that traditional wisdom concerning the design and grouping of environmental policy instruments can actually be questioned (Greaker 2004, Copeland 2005, David and Sinclair-Desgagné 2005, Canton et al. 2007). This article thus seeks to re-examine in particular the well-known

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[1] For data and figures concerning the environment industry and its various segments, see the reports by the Organization for Economic Cooperation and Development/Eurostat (1992, 1996 and 1999), the World Trade Organization (1998), and Environmental Business International (2006).

combination of a tax on polluting emissions with a subsidy. Intuitively, this mixture of instruments might alleviate the two distortions which are present here, i.e. the one that comes from pollution and the other that is due to the environment firms' market power. We will show that, because of the latter, enacting an emission tax together with a subsidy to polluters cannot achieve the first-best. The opposite positive conclusion obtains, however, if the subsidy is granted instead to environment firms. When public transfers are themselves subject to distortions, welfare may finally be higher if only the tax is used.

The paper is organized as follows. The upcoming section presents our model. Section 3 considers next the benchmark first-best case. The policy of mixing an emission tax with a subsidy to polluters is analyzed in section 4. Section 5 then looks at the possibility of subsidizing instead the environment firms. Section 6 re-assesses this combination of policy instruments if public transfers are themselves subject to distortions. Section 7 offers some concluding remarks and discusses future research topics.

2. The model

As in David and Sinclair-Desgagné (2005), let us consider a representative price-taking firm that produces one consumption good and sells it on a competitive market at unit price P. The cost of producing quantity x of the consumption good is given by $C(x)$; the function $C(\cdot)$ is assumed to be twice differentiable, strictly increasing and convex.

While it manufactures and delivers the consumption good, the firm also generates pollution. At output level x, the amount of polluting emissions is given by the function $e(x, a)$, where a represents the firm's abatement effort. To simplify the analysis without losing much in realism, we shall say that abatement essentially consists in end-of-pipe measures.[2] The emission function can then be set as an additively separable expression of the form $e(x,a) = w(x) - \epsilon(a)$. We suppose that $w'(x) > 0$, meaning that greater production creates more pollution, $\epsilon'(a) > 0$, so more abatement decreases total emissions, $w''(x) \geq 0$, so that emissions from the last unit produced increase with production, and $\epsilon''(a) < 0$, meaning that abatement is subject to diseconomies of scale.

By contrast with usual economic modelling, let us now assume that the representative polluting firm cannot make for itself the needed abatement goods and services; it must instead procure these goods and services from a specialized eco-industry. This industry comprises n identical firms competing à la Cournot. An individual environment firm i incurs a cost $G(a_i)$ for delivering quantity a_i of abatement goods and services, where the function $G(\cdot)$ is twice differentiable, strictly increasing and convex.

Let $q(a)$ denote the inverse demand function faced by the environment industry, where a stands for total purchases of abatement goods and services. Each environment firm's profit is now given by

$$\Pi_i = q(a)a_i - G(a_i) \quad , \quad i = 1, ..., n$$

and the Cournot-Nash equilibrium must satisfy the following first-order conditions

$$\frac{\partial q}{\partial a} a_i + q(a) - G'(a_i) = 0 \quad , \quad i = 1, ..., n. \tag{1}$$

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[2] The report by the European Commission (1999), for instance, reveals that end-of-pipe activities, such as solid waste management, waste-water treatment, air pollution control and contaminated soil and groundwater remediation, remain by far the most significant segment of the eco-industry, accounting for more than 60% of total industry income.

Since all environment firms are similar, we have that $a_i = \frac{a}{n}$ at equilibrium.[3] Let $a' = \frac{\partial a}{\partial q}$; equation (1) can now be re-written as

$$q(a) = G'(a_i) - \frac{a}{n}.\frac{1}{a'} \quad , \quad i = 1, ..., n \ . \tag{2}$$

As it is common in Cournot competition, the market price is equal to the marginal cost plus a markup.[4]

This completes the basic description of the model. As a benchmark case, we shall now briefly consider first-best production and abatement levels.

3. The first-best

Each unit of polluting emissions causes society an amount of harm v. Pollution, however, can be regulated by a benevolent regulator who balances consumer surplus, firm profits and pollution damages. At the first-best, the regulator would select consumption level x and abatement effort a in order to maximize the welfare function

$$W = \int_0^x P(u)du - C(x) - nG(\frac{a}{n}) - v[w(x) - \epsilon(a)].$$

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[3] We suppose that the Cournot-Nash equilibrium exists and is unique. This is ensured when the profit functions Π_i are concave in a_i, i.e., when we have $\frac{\partial^2 q}{\partial a^2} a_i + 2\frac{\partial q}{\partial a} - G'' \leq 0$.

[4] The derivative a'represents the variation of demand for abatement when the price of abatement goods and services increases; its sign is thus expected to be negative. This will be verified in the next section.

The first-order conditions for welfare maximization are now

$$\begin{aligned} P(x^*) - C'(x^*) - vw'(x^*) &= 0, && (3) \\ -G'(\frac{a^*}{n}) + v\epsilon'(a^*) &= 0. && (4) \end{aligned}$$

According to (3), the price of the consumption good is then equal to its marginal cost plus the amount of environmental damage due to production. Equation (4) says, furthermore, that abatement goods and services are delivered up to the point where the marginal cost of abatement efforts meets their marginal social benefit.

With respect to first-best, a profit-maximizing polluting firm will naturally produce too much and abate too little. This firm will behave as if solving the problem

$$\max_{x,a} \quad \pi = Px - C(x) - qa \quad , \tag{5}$$

thereby selecting the output level x° at which the marginal production cost $C'(x^\circ)$ is equal to the market price P, and setting abatement orders at $a^\circ = 0$. To correct for this, the regulator can rely on various policy instruments in order to provide proper incentives. In the present context, David and Sinclair-Desgagné (2005) have examined, for instance, the respective effect of emission taxes, technical standards and voluntary approaches. The co-existence of two distortions - the negative externality caused by pollution and the exercise of market power by environment firms - suggests, however, that two policy instruments should be used simultaneously. In the upcoming sections, we shall then consider specific ways to combine a tax and a subsidy.

4. Taxes and subsidies are for polluters

To begin with, let the regulator set a tax t per unit of emissions while granting the polluting firm a subsidy s for each unit of abatement effort. Suppose for the moment that both the tax revenue and the subsidy are handled in a neutral way.

The representative polluter's profit is now

$$\pi = Px - C(x) - qa - t[w(x) - \epsilon(a)] + sa.$$

Its answer to this policy is then captured by the following profit-maximizing first-order conditions:

$$\begin{aligned} P - C'(x^{ts}) - tw'(x^{ts}) &= 0 &\quad (6)\\ -q + t\epsilon'(a^{ts}) + s &= 0. &\quad (7)\end{aligned}$$

After comparing (6) and (7) with (3) and (4), one concludes that, in principle, the first-best could be reached with a tax-subsidy scheme of the form

$$\begin{aligned} t^* &= v \\ s^* &= q - G'(\frac{a^*}{n}), \qquad (8)\end{aligned}$$

i.e. by combining the pigouvian tax with an abatement subsidy equal to the eco-industry's markup at equilibrium. Equation (2) implies that the latter can be written as

$$s^* = \frac{a^*}{n}(-\frac{1}{a'_{ts}}),$$

where a'_{ts} is the price-derivative of demand for abatement services when the polluter pays a tax t and receives a subsidy s. The term a'_{ts} is obtained by totally differentiating expression (7); it is actually given by

$$a'_{ts} = \frac{da^{ts}}{dq} = \frac{1 - \frac{ds}{dq}}{t\epsilon''}.$$

Equation (8), however, entails that $\frac{ds}{dq} = 1$. This means that a'_{ts} has to be close to 0, so the subsidy s^* should tend to $+\infty$.

Intuitively, implementing the first-best requires that the subsidy be equal to the eco-industry's markup. Any increase in the price q of abatement goods and services must therefore be exactly compensated by an augmentation in the subsidy s. As a result, the polluter's demand for abatement becomes insensitive to price, or the price-elasticity of demand for abatement tends to zero. This confers maximal market power to environment firms, who will then raise their price as long as the regulator covers the bill. This finding constitutes our first proposition.[5]

PROPOSITION 1. *When abatement goods and services are supplied by an imperfectly competitive eco-industry, taxing polluting emissions while directly subsidizing the polluter's abatement efforts grants maximal market power to the eco-industry; the amount of subsidy necessary to achieve the first best is then unbounded.*

In practice, this situation would of course hardly be sustainable. Most constituencies would oppose turning public funds into huge eco-industry profits, and the regulator would

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[5] This result still holds when there is free entry in the eco-industry. A proof can be found in the appendix.

find it impossible to collect enough money to pay the subsidy. The regulator will then have to put a ceiling on the subsidy, thereby limiting the eco-industry's market power but encouraging insufficient abatement. To somewhat counterbalance this, she might increase the tax above the pigouvian level. A second-best situation will result, with insufficient pollution abatement and consumption good delivery.

Let us now consider what appears to be the closest alternative to this policy.

5. Taxes are for polluters, subsidies go to the eco-industry

By contrast with the previous section, suppose the regulator imposes a tax t per unit of emissions but grants the subsidy s per abatement unit to environment firms. Public funds are again managed in a neutral way.

The representative polluter now makes profits according to

$$\pi = Px - C(x) - qa - t[w(x) - \epsilon(a)], \tag{9}$$

so its reaction is captured by the first-order conditions

$$\begin{aligned} P - C'(x^t) - tw'(x^t) &= 0 && (10) \\ -q + t\epsilon'(a^t) &= 0. && (11) \end{aligned}$$

Comparing these equations with expressions (3) and (4) suggests that the optimal tax has to be set at the pigouvian level $t = v$ if $q = G'(\frac{a}{n})$.

Notice now that an environment firm's profit is currently

$$\Pi_i = q(a)a_i - G(a_i) + sa_i \quad ,$$

so it will supply an amount of abatement goods and services a_i that satisfies the equation

$$q^s(a) = G'(a_i) + \frac{a}{n}(-\frac{1}{a'}) - s \quad . \tag{12}$$

The regulator might then establish its subsidy as

$$s^* = \frac{a}{n}(-\frac{1}{a'}) \quad ,$$

in order for the charged price of abatement goods and services to correspond to the marginal cost $G'(\frac{a}{n})$.

Indeed, the first-best will be reached here with the following tax-subsidy combination

$$\begin{aligned} t^* &= v \\ s^* &= \frac{a^*}{n}(-\frac{1}{a'_t}) \ . \end{aligned} \tag{13}$$

This scheme looks quite similar to the previous one: the proposed emission tax matches the marginal social cost of pollution, while the subsidy corresponds to the eco-industry's markup. Because it is attributed to environment firms, however, this subsidy turns out to have an upper-bound. To see this formally, note that the denominator term a'_t, which is again the price-derivative of the polluter's demand for abatement under a tax t and is obtained by differentiating totally equation (11), is now given by $a'_t = \frac{da^t}{dq} = \frac{1}{t\epsilon''}$. With the emission tax set at the pigouvian level, we have that $a'_t = \frac{1}{v\epsilon''}$, which is generally bounded away from 0, so the subsidy

$$s^* = \frac{a^*}{n}(-v\epsilon'')$$

is obviously a finite quantity. This results yields our second proposition.

Proposition 2. *When abatement goods and services are supplied by an imperfectly competitive eco-industry, combining an emission tax with a limited subsidy to environment firms can implement the first-best.*

To enact this policy, the regulator must of course know the marginal social cost of pollution v and have information about the cost $G(\cdot)$ and impact $\epsilon(\cdot)$ of using the relevant abatement goods and services. There might also be administrative costs in trying to combine and coordinate instruments (see Carraro and Metcalf 2001). An important aspect of the latter issue will now be considered.

6. Public fund transfers are costly

Let us now lift the assumption made so far that handling public funds involves no economic distortions. Following Laffont and Tirole (1993), the social cost of public monetary transfers will be captured by a parameter $\lambda \in [0, 1]$. When gathering tax revenues, a portion λ of it will be lost. Similarly, while allocating subsidies, a fraction λ of the total will fail to reach the intended recipients.

The regulator then faces a trade-off between (1) using the emission tax only, which leads to insufficient output and abatement (see David and Sinclair-Desgagné, 2005) and also entails a loss while collecting taxes, and (2) using a tax-subsidy scheme, which better deals with pollution and the eco-industry's market power but creates additional distortions when part of the subsidies is burnt up in the allocation process.[6] The former policy yields social welfare

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - nG(\frac{a^t}{n}) - v[w(x^t) - \epsilon(a^t)] - \lambda t[w(x^t) - \epsilon(a^t)] \ . \qquad (14)$$

The tax-subsidy combination, on the other hand, delivers social welfare levels equal to

$$W^{ts} = \int_0^{x^{ts}} P(u)du - C(x^{ts}) - nG(\frac{a^{ts}}{n}) - v[w(x^{ts}) - \epsilon(a^{ts})] - \lambda t[w(x^{ts}) - \epsilon(a^{ts})] - \lambda s a^{ts} \ . \quad (15)$$

Comparing (14) and (15) is not straightforward. Which policy is better depends on the extent of the distortion due to imperfect competition in the eco-industry (which is driven by the number n of environment firms), compared to the negative externality from pollution (captured by v) and the cost of public fund transfers (given by λ).

Some ranges of parameter values that make one policy better than the other are

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[6] There is no point here in examining a policy consisting of an environmental subsidy only. Without an emission tax (or any other regulatory constraint), the representative polluter's demand for abatement would vanish and all specialized producers of abatement goods and services would cease to exist.

depicted in Figure 1. The computations which support this figure can be found in the appendix; they use the peculiar functional forms $P(x) = 10 - x$, $C(x) = \frac{1}{2}x^2$, $G(a) = a$, and $e(x, a) = x - \sqrt{a}$. The first graph concerns smaller values of λ, and the second graph larger ones (i.e., $\lambda_1 > \lambda_0$). The area labelled with the letter T corresponds to the values of n, v, and λ for which using the emission tax alone is more efficient. The region tagged as TS, on the other hand, spans the ranges of parameter values for which the tax should rather go with a subsidy. The hatched area, finally, indicates the circumstances when, given the cost of public intervention, neither a tax nor a subsidy should be applied. Some key conclusions to be drawn from the figure are now summarized in our last proposition.

Insert Figure 1 about here

Proposition 3: *Combining an emission tax and a subsidy to the eco-industry is more efficient than using an emission tax alone when the number of firms n in the eco-industry and the marginal social cost of pollution v are not too high. The set of pairs (n,v) for which a tax-subsidy scheme is more efficient tends to shrink as the social cost of public funds λ increases.*

An intuitive explanation of these results would run as follows. First, observe that the hatched area in the figure covers a region where v takes low values. Clearly, when the negative externality caused by pollution is small relative to the social cost of public funds λ, it is suboptimal to impose a tax on emissions given the low benefit and high cost of such a measure. But without an emission tax, no abatement activity takes place and subsidizing environment firms is pointless (since these firms do not even have a market). For low values on v, therefore, neither a tax nor a subsidy should be used. For high values of v and n, on the other hand, social welfare would be higher under a tax on polluting emissions with no accompanying subsidy. In this case, pollution is more detrimental to social welfare than imperfect competition in the eco-industry (since the presence of a high number of environment firms means that competition in the eco-industry is relatively strong), so the regulator should concentrate on dealing with the environmental externality given the cost of handling public funds. In contrast, when n is rather small, the distortion caused by an imperfectly competitive eco-industry becomes significant enough to make the tax-subsidy worthwhile. The area where such a combination is finally preferable decreases as λ increases, since the combination of both instruments becomes then more costly compared to a tax-only policy.

7. Concluding remarks

This paper investigated the combination of an emission tax and an environmental subsidy when abatement goods and services are supplied by an imperfectly competitive eco-industry. The environmental economics literature has implicitly assumed so far that abatement subsidies can only be granted to polluters. We just showed that such a policy could hardly implement the first-best in the presence of an oligopolistic environment industry. A much cheaper way to do so is to subsidize environment firms, not the polluters. If public transfers are also subject to significant administrative costs, however, the regulator will want to suppress all environment subsidies when the number of environment firms is relatively large (so competition in the eco-industry remains strong).

The policy of subsidizing abatement efforts may need further qualifications after one considers general equilibrium effects (Parry 1997) or international trade agreements. Our basic conclusions, however, seem to hold under more realistic assumptions concerning the eco-industry, such as free entry or monopolistic competition. Studying the consequences of other relevant and more complex industry structures, however, (with asymmetric environment firms or when polluters are also able to make their own abatement goods, notably) will require additional research.

Appendix

▶ Robustness of Proposition 1 with free entry

Assume there is free entry in the eco-industry and any producer of abatement goods and services incurs a fixed cost F. The profit of a firm in the environment industry is now

$$\Pi_i = q(a)a_i - G(a_i) - F \ .$$

In this case, the first-order condition for profit maximization is

$$q(a) = G' + \frac{a}{n}(-\frac{1}{a'}) \ , \qquad (16)$$

where $a' = \frac{\partial a}{\partial q} < 0$, and the number of firms in the eco-industry is determined by the zero-profit condition

$$q(a)a_i - G(a_i) - F = 0 \ .$$

When the regulator implements an emission tax and an abatement subsidy to polluting firms, the profit of a typical polluter is

$$\pi = Px - C(x) - qa - t[w(x) - \epsilon(a)] + sa \ ,$$

which yields the following first-order conditions for profit maximization

$$\begin{aligned} P - C'(x) - tw'(x) &= 0 \\ -q + t\epsilon'(a) + s &= 0 \ . \end{aligned} \tag{17}$$

In order to achieve the first-best, the regulator would then have to set

$$\begin{aligned} t^* &= v \\ s^* &= q - G'. \end{aligned} \tag{18}$$

By equation (2), the latter is equivalent to $s^* = \frac{a}{n}(-\frac{1}{a'})$. The derivative a' comes from totally differentiating equation (17) and is equal to $a' = \frac{1-\frac{ds}{dq}}{t\epsilon''}$. Equation (18) implies that $\frac{ds}{dq} = 1$, so a' has to be very small and the optimal subsidy s^* must again be unbounded.

▶ Social welfare with a tax-only policy, when public transfers are costly

Using the functional forms $P(x) = 10 - x$, $C(x) = \frac{1}{2}x^2$, $G(a) = a$, and $e(x, a) = x - \sqrt{a}$, the polluting firm's output and abatement demand when facing a tax t are respectively

$$x^t = \frac{10 - t}{2} \quad , \quad a^t = (\frac{t}{2q})^2 \quad . \tag{19}$$

The derivative $a'_t = \frac{\partial a^t}{\partial q}$ is thus given by

$$a'_t = -\frac{t^2}{2q^3} \ .$$

Given these expressions, the equilibrium price of abatement goods and services is

$$q^t = \frac{2n}{2n - 1} \ ,$$

and the corresponding purchases by the representative polluter amount to

$$a^t = \frac{t^2(2n - 1)^2}{16n^2} \ .$$

Recall now that social welfare is given by

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - nG(\frac{a^t}{n}) - v[w(x^t) - \epsilon(a^t)] - \lambda t[w(x^t) - \epsilon(a^t)] \ .$$

Maximizing this function with respect to t under the constraint $t \geq 0$, taking into account the reactions x^t and a^t indicated in (19), yields the following formula for the optimal tax

$$t_T(\lambda, v, n) = \frac{8(v-5\lambda)n^2 - 2vn}{8n^2(1-2\lambda) - 4n(1-\lambda) + 1} \tag{20}$$

if this expression is positive, and $t_T(\lambda, v, n) = 0$ otherwise. The optimal welfare under a tax-only policy is then obtained by substitution.

▶ **Welfare with the tax-subsidy policy, when public transfers are costly**

Here, the representarive polluter's output and abatement demand are respectively given by

$$x^t = \frac{10-t}{2} \ , \ \ a^t = (\frac{t}{2q})^2 \ \ , \tag{21}$$

and the derivative

$$a' = -\frac{t^2}{2q^3} \quad .$$

Given these expressions, and the eco-industry's behavior in this case as characterized by equation (12), the equilibrium price for abatement goods and services becomes

$$q^t = \frac{2n(1-s)}{2n-1} \ ,$$

so the associated quantity of procured abatement products is

$$a^t = \frac{t^2(2n-1)^2}{16n^2(1-s)^2} \quad .$$

Now, social welfare can be represented as

$$W^{ts} = \int_0^{x^{ts}} P(u)du - C(x^{ts}) - nG(\frac{a^{ts}}{n}) - v[w(x^{ts}) - \epsilon(a^{ts})] - \lambda t[w(x^{ts}) - \epsilon(a^{ts})] - \lambda s a^{ts} \ .$$

Maximizing this function with respect to s and t, given nonnegativity constraints and the reactions x^t and a^t shown in (21), gives the following equations

$$-4v - 4t\lambda + \frac{(2n-1)t}{n(1-s)}(2 + \lambda + s\lambda) = 0 \ ,$$

$$\begin{aligned} & 2(2n-1)v + 4[(v - 10\lambda)n(1-s) + (2n-1)t\lambda] \\ & + \frac{t}{n(1-s)}[-1 - s\lambda + 4n(1 + s\lambda) + 4n^2(s(2 - 5\lambda) + 2(-1 + \lambda) + s^2(-1 + 2\lambda))] = 0 \quad . \end{aligned}$$

Solving this system yields the optimal subsidy

$$s_{TS}(\lambda, v, n) = \frac{8\lambda(3v + 5\lambda - 10)n^2 + (20\lambda^2 + 40\lambda - 10\lambda v - 4v)n + \lambda v}{4(30\lambda^2 + \lambda v - 2v)n^2 + 2\lambda(v - 10\lambda)n} \tag{22}$$

if this expression is positive ($s_{TS}(\lambda, v, n) = 0$ otherwise), and the optimal emission tax

$$t_{TS}(\lambda, v, n) = \frac{n^2(160\lambda(1 + \lambda) - 8v(5\lambda + 2)) + 4\lambda v n}{4n^2(17\lambda^2 + 4\lambda - 4) - 12\lambda^2 n + \lambda^2} \tag{23}$$

if this ratio is positive (or else $t_{TS}(\lambda, v, n) = 0$). Optimal welfare levels under a tax-subsidy policy can then be computed by substitution.

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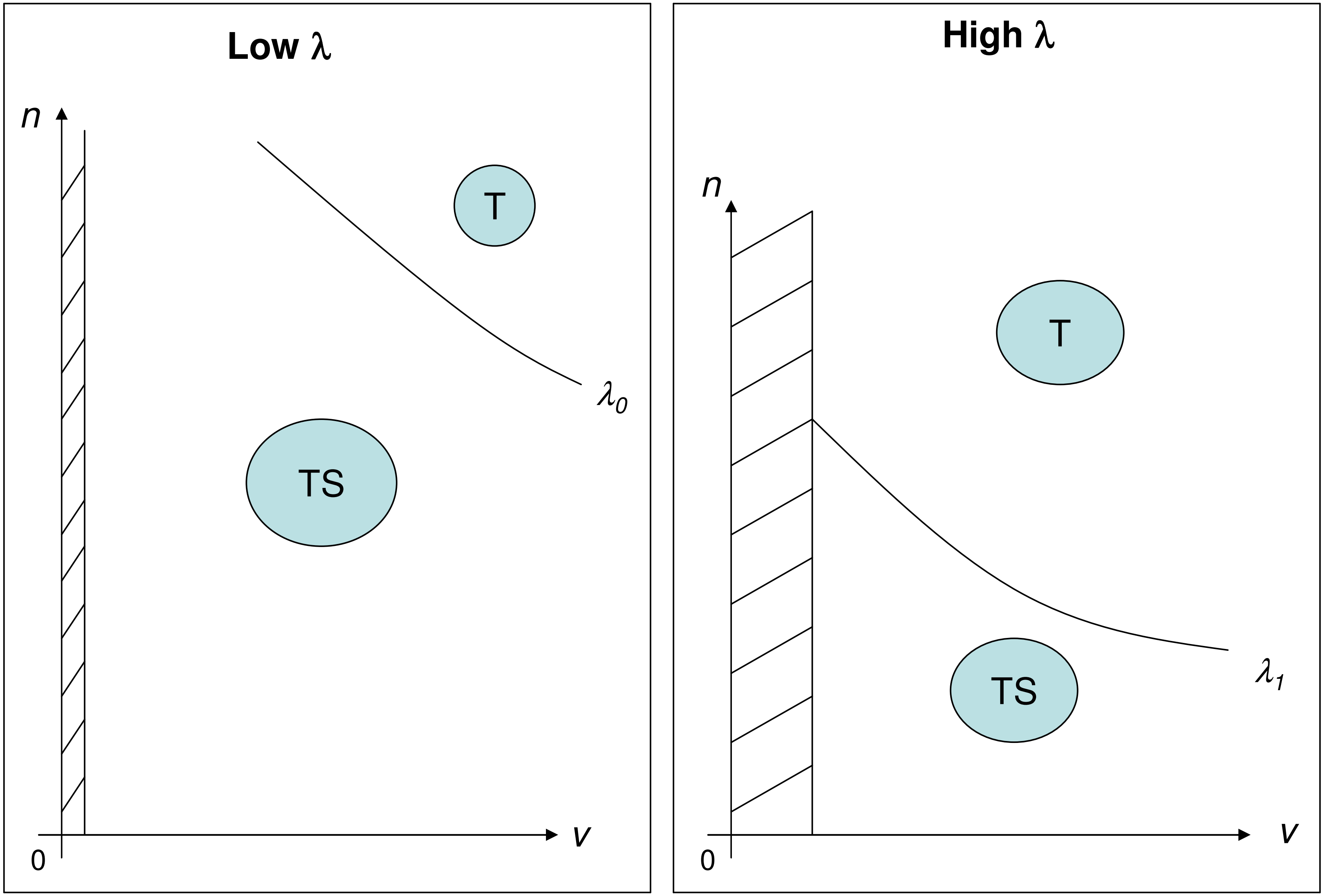

Figure 1. Tax alone vs. tax-subsidy combination