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Revisiting the Environmental Subsidy in the Presence of an Eco-Industry

M. David, B. Sinclair-Desgagné

UMR Economie Publique
Avenue Lucien Brétignières – 78850 Grignon
16 rue Cl. Bernard – 75005 Paris
Tel. +33 (0)1 30 81 53 30
Fax. +33 (0)1 30 81 53 68
http://www.grignon.inra.fr/economie-publique

Revisiting the Environmental Subsidy in the Presence of an Eco-Industry

Maia David* and Bernard Sinclair-Desgagné†

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This paper re-considers environmental subsidies in the context where polluting firms procure their abatement goods and services from a specialized oligopoly. In order to maximize social welfare, a 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 the combination of an emission tax and a subsidy to polluters cannot achieve the first-best, while the opposite positive conclusion obtains 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.

KEYWORDS: Environmental subsidies, Pigouvian taxes, environment industry

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*UMR INRA-INAPG Economie Publique, France. mdavid@inapg.fr

†CIRANO, CIRAIG, and HEC Montréal, Canada.

1 Introduction

Environment 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 inferior to pollution taxes (Fredriksson 1997), and ultimately encourage pollution (Kohn 1992), while supporters claim that they might fulfill redistribution objectives (Fredriksson 1997), accelerate the transfer of cleaner technologies (Stranlund 1997), and strictly enhance social welfare when combined with taxes (Kohn 1991, Conrad 1993, Fullerton and Mohr 2002)

In all previous studies (as in all environmental economics so far), polluters were assumed to know and pay exactly the cost of abatement goods and services. However, pollution abatement good and services are now largely being delivered by a specialized environment industry. In 1997, this industry totalled earnings of $350 billions, and this figure has been projected to double by 2010.[1] Several studies reveal, furthermore, that the various segments of the eco-industry are imperfectly competitive (Karliner 1994, Barton 1997), which means that environment firms can charge a markup to their polluting clients.

Recent papers that took these stylized facts into account suggest that traditional wisdom concerning the design and combination of environmental instruments needs to be re-examined (Greaker 2004, Copeland 2005, David and Sinclair-Desgagné 2005). This article now seeks to re-examine the standard possibility of combining a tax on polluting emissions with a subsidy. Intuitively, this combination of precisely two 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 find that, because of the environment firms's market power, the combination of an emission tax and a subsidy to polluters cannot achieve the first-best. An opposite positive conclusion obtains, however, if the subsidy is granted instead to environment firms. When public transfers are themselves subject to distortions, welfare may actually be higher if only an emission tax is used.

The paper is organized as follows. Our model is presented in the next section. Section 3 briefly considers the benchmark first-best case. The combination of an emission tax and a subsidy to polluters is analyzed in section 4. Section 5 then studies a policy of subsidizing instead the environment firms. Section 6 re-assesses the combination of instruments when public transfers are themselves subject to distortions. Section 7 concludes the paper.

[1] See the reports by the Organization for Economic Cooperation and Development/Eurostat (1992, 1996 and 1999) and the World Trade Organization (1998).

2 The model

Following David and Sinclair-Desgagné (2005), we consider a representative price-taking firm that produces one consumption good and sells it on a competitive market at a price per unit P. The production cost associated with a quantity x of the consumption good is given by $C(x)$, a function that is twice differentiable, strictly increasing and convex.

Along with the consumption good, the firm also produces some pollutant. At an output level x, the amount of polluting emissions is given by $e(x, a)$, where a represents the firm's abatement effort. Without much loss in realism, let abatement concentrate on end-of-pipe measures, so the emission function can take the additively separable representation $e(x, a) = w(x) - \epsilon(a)$. We assume that $w'(x) > 0$ (more production entails more pollution), $\epsilon'(a) > 0$ (more abatement decreases total emissions), $w''(x) \geq 0$ (emissions from the last unit produced increase with the production level), and $\epsilon''(a) < 0$ (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 abatement goods and services it needs. It must then procure these goods and services from a specialized environment industry. This industry comprises n identical firms competing à la Cournot. An individual environment firm i incurs a cost $G(a_i)$ for delivering a quantity a_i of abatement goods and services, where $G(.)$ is twice differentiable, strictly increasing and convex.

Let $q(a)$ denote the inverse demand function faced by the environment firms, where a stands for total purchases of abatement goods and services. An environment firm i's profits are now given by.

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

The Cournot-Nash equilibrium is given by the following first-order condition

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

Since all environment firms are similar, we have that $a_i = \frac{a}{n}$ at an equilibrium.[2] Let $a' = \frac{\partial a}{\partial q}$; equation (1) can now be re-written as

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

[2] 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 $\frac{\partial^2 q}{\partial a^2} a_i + 2\frac{\partial q}{\partial a} - G'' \leq 0$.

As is common in Cournot competition, the market price is equal to the marginal cost plus a margin[3]. This completes the basic description of the model. As a benchmark case, we shall now briefly consider the first-best production and abatement levels.

3 First-best

The downside of polluting emissions is that each unit causes society an amount of harm v. The latter, however, can be regulated by a benevolent regulator who will balance the sum of consumer surplus and firms' profits with pollution damages. In a first-best equilibrium, the regulator would then select consumption x and abatement a in order to maximize the welfare function

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

The first-order conditions for welfare maximization are now

$$P(x^*) - C'(x^*) - vw'(x^*) = 0, \tag{3}$$

$$-G'(\frac{a^*}{n}) + v\epsilon'(a^*) = 0 \tag{4}$$

The optimal price for the consumption good is equal to its marginal production cost plus a parameter which takes into account the environmental damage of producing this good (equation (3)). The optimal abatement level in the economy is given at the point where the marginal abatement cost equalizes the marginal social benefit of abatement (equation (4)).

If the polluting firm is left to maximize its profits, i.e., to solve

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

it will surely select the output level x^0 where the marginal production cost $C'(x^0)$ equals the market price P of the consumption good, while setting its abatement orders at $a^0 = 0$. It will then produce too much and will not abate enough.

Of course, in the real world the regulator cannot dictate the first-best levels of consumption and abatement. She will then relate on policy instruments such as taxes and subsidies to provide proper incentives to economic agents. David and Sinclair-Desgagné (2005), Nimubona and Sinclair-Desgagné (2005)

[3] a', which represents the variation of abatement demand when its price increases, is generally negative. This is verified in the following section.

and Canton, Soubeyran and Stahn (2005) have examined the environmental tax in this framework. However here the co-existence of two distortions, namely the pollution and the imperfect competition in the eco-industry, motivates the use of a two-intrument policy. Let us look into the combination of a tax and a subsidy.

4 First case: polluters are subject to an emission tax and an abatement subsidy

Let the regulator impose on polluters a tax t per unit of emissions, while each unit of abatement effort receives a subsidy s. We assume for the moment that both the subsidy and the tax revenue are collected and granted in the economy in a neutral way.

The representative polluter's profit now becomes

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

The polluter's reaction to this policy is then captured by the following first-order conditions:

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

In principle, the first-best could be reached with the following combination of a tax and a subsidy (see equation (3) in comparison with equation (6) and equation (4) in comparison with (7)):

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

i.e. by implementing the Pigouvian tax rate (Pigou, 1920) and an abatement subsidy equal to the mark-up of the eco-industry at the equilibrium.

However, the environment firms' reaction given by (2) entails that the eco-industry's mark-up, and thus the optimal abatement subsidy, must be given by

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

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

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

Given (8), we have that $\frac{ds}{dq} = 1$. Hence, a'_{ts} tends towards 0 and

$$s^* \to +\infty$$

This result means that, as the subsidy on abatement compensates any rise in the price q, the polluter's abatement demand is not affected by a price increase. In other words, the price elasticity of demand for abatement tends towards zero, which confers maximal market power to environment firms. As a consequence, these firms will rise their price as long as the regulator takes the bill. This implies that reaching the first-best would require an infinite amount of subsidy.

Naturally, this situation is not viable in the real world. First, it is impossible to collect unlimited funds to finance the subsidy. Second, it is not even politically acceptable to use public funds to nourish tremendous profits for the eco-industry. The public regulator would then have to set a second-best subsidy below s^* which would limit the eco-industry's market power but which would lead to insufficient abatement ($a^{ts} < a^*$). The regulator would then have to increase the tax compared to the first-best level in order to compensate for the sub-optimal subsidy. We would then reach a second-best situation, with insufficient abatement and insufficient production of the consumption good.

As a conclusion, the combination of an emission tax and an abatement subsidy to polluters does not allow to reach the first best.

Proposition 1. *When the abatement good or service is supplied by an imperfectly competitive eco-industry, subsidizing the polluters' abatement yields maximal market power to the eco-industry so reaching the first-best would necessitate an infinite subsidy. Only a second-best can then be reached, leading to insufficient abatement and insufficient production of the consumption good.*

This result remains valid when there is free entry in the eco-industry (see the appendix for a quick proof).

Let us now consider the main alternative to this policy.

5 Second case: the subsidy goes to the environment industry

Let the subsidy s be given now directly to environment firms.

The polluter's profit is written:

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

and its reaction to the tax is captured by the first-order conditions

$$P - C'(x^t) - tw'(x^t) = 0 \quad (10)$$
$$-q + t\epsilon'(a^t) = 0 \quad (11)$$

Comparing these equations with (3) and (4), if $q = G'(\frac{a}{n})$, the optimal tax rate is the Pigouvian rate $t = v$.

On the other hand, the profit of a firm in the eco-industry is now

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

so it will deliver an amount of abatement goods and services that solves the equation

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

In order to correct the distortion due to imperfect competition within the eco-industry, the regulator must set a subsidy such as

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

where a' is the price derivative of the polluter's abatement demand. The price of the abatement good or service is then equal to the perfectly competitive price $q^s = G'(\frac{a}{n})$.

In the present context, the first-best can thus be reached with the following combination of a tax and subsidy

$$t^* = v$$
$$s^* = \frac{a^*}{n}(-\frac{1}{a_t'})$$

We have that[4] $a_t' = \frac{da^t}{dq} = \frac{1}{t\epsilon''}$. When the emission tax is set optimally, $a_t' = \frac{1}{v\epsilon''}$ and

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

The optimal tax rate is the same as in the previous case. Contrarily to the above, however, the optimal subsidy is now limited.

Proposition 2. *When abatement goods and services are supplied by an imperfectly competitive environment industry, a combination of an emission tax and a limited subsidy on the eco-industry's output can implement the first-best.*

[4]This is obtained by differentiating totally (11).

Of course, in order to implement this policy the regulator must detain information on v and on the abatement technology (in order to know a^*, which depends on G, and ϵ''). It is quite reasonable to assume that the characteristics of the abatement technology are approximately known by the decision maker. Regarding the social damage associated to pollution, many methods exist in order to evaluate it and, even though these methods only allow for an approximation, we shall assume the regulator knows v. Assuming the regulator detains the necessary information, a subsidy to the eco-industry as a complement to an emission tax allows to reach the first-best. In the framework of our model, it is then recommended to implement this type of subsidy rather than a subsidy to the polluting industry.

The first-best can be reached when the regulator faces multiple distortions by combining certain policy instruments. However, these combinations do not seem very widely spread although multiple distortions is the most common framework in real life. This may be explained by the increased cost and administrative complexity of combining instruments compared to single instrument policies (see Carraro and Metcalf, 2001). The upcoming section takes these issues into account.

6 Third case: public fund transfers are costly

In this section, we assume that transferring funds imply administrative inefficiencies and economic distortions which are captured by a parameter λ where $\lambda \in [0, 1]$ (see for instance Laffont and Tirole, 1993). When redistributing the tax revenue, a portion λ of this revenue is lost. Equivalently, a portion λ of the funds collected for the subsidy is lost. The regulator now faces a trade-off between:

- using the emission tax only, which leads to insufficient output and insufficient abatement (see David and Sinclair-Desgagné, 2005) and implies a cost due to the tax revenue transfer;

- or using a combination of an emission tax and a subsidy to the eco-industry, which corrects both distortions but duplicates public fund transfers.

Let us now compare these two policies, namely the use of an emission tax alone and the combination of instruments. There is no point in examining a policy composed only of the subsidy as, when no emission taxes are applied, the polluters' demand for abatement is equal to zero and the eco-industry does not even exist. Our comparison is based on a comparison of social welfare, which are written:

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - nG(\frac{a^t}{n}) - v[w(x^t) - \epsilon(a^t)] - \lambda t[w(x^t) - \epsilon(a^t)] \quad (13)$$

when the tax is used alone, and:

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

when the tax is combined with a subsidy.

The comparison of both policies is not straightforward. It depends on the extent of the distortion due to an imperfectly competitive eco-industry (represented by n), of the distortion due to pollution (represented by v) and on the level of the cost of public fund transfers (represented by λ). In order to determine with more precision the weight of each effect, we need to add structure to the model and use specific functions. Let $P(x) = 10 - x$; $C(x) = \frac{1}{2}x^2$; $G(w) = w$; and $e(x, a) = x - \sqrt{w}$.

The first step to reach our objective is to study the optimal tax and subsidy rates. These actually differ from the one obtained in David and Sinclair-Desgagné (2005) (for the tax alone) and in the section 5 (for the combination of a tax and a subsidy) as they must now take into account the presence of the parameter λ. The tax and subsidy rates are lower than the one obtained when $\lambda = 0$, due to the additional cost these instruments now generate. The expressions for the optimal tax when used alone, $t^*(\lambda)$, the optimal tax when combined with the subsidy, $t^*_s(\lambda)$, and the optimal subsidy $s^*(\lambda)$ are given in the appendix.

Given these optimal rates, we determine the equilibrium values x^t, a^t, x^{ts} and a^{ts}. We then use the expressions (13) and (14) in order to obtain both welfare values as a function of n, v and λ. For a wide range of values on λ we then compare W^t and W^{ts} for different combinations on n and v. Our results are represented in the plan (v, n) as shown in Figure 1.

In Figure 1, the area denoted as T represents the set of values for which the emission tax is more efficient when used alone than when combined with the subsidy. The area denoted as TS represents the set of values for which the tax should be combined with the subsidy. The hatched area corresponds to the situation when, given the cost of public intervention, neither a tax nor a subsidy should be applied. The first graph applies for low λ-values whereas the second graph applies for higher λ-values.

This yields the following proposition:

Proposition 3. *Combining an emission tax and a subsidy to the eco-industry's output is more efficient than an emission tax alone when the number of firms*

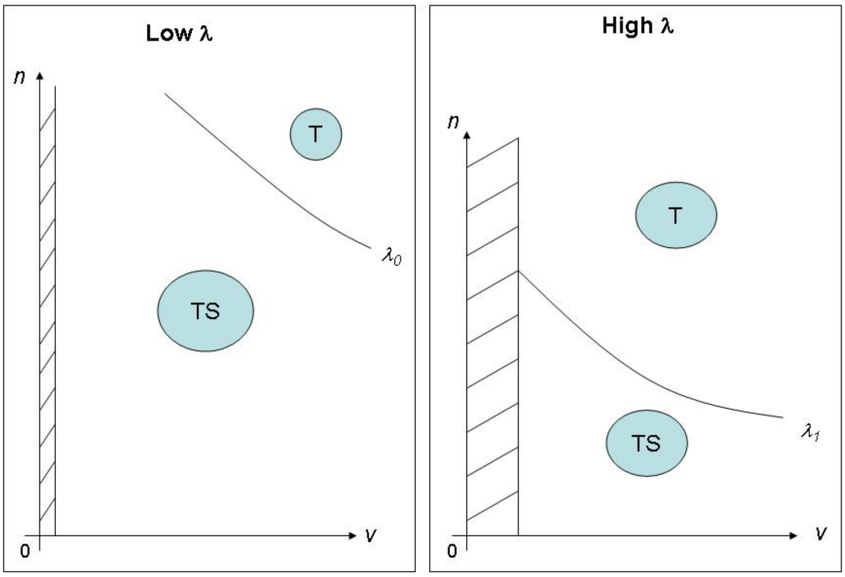

Figure 1: Comparison of a tax and a combination of a tax and subsidy

in the eco-industry (n) and the social damage due to pollution (v) are not too high. The set of values on n and v for which the combination of instruments is more efficient than the tax decreases as the social cost of public funds (λ) increases.

The intuition associated to these results is the following. First, we note that the hatched area in Figure 1 is observed for low values on v. This is due to the fact that when the distortion due to pollution is low compared to the social cost of public funds, it is better not to introduce a tax on pollution in order to avoid the costs it generates. Moreover, when no tax is applied, there is no point in applying a subsidy as no abatement activity occur. Therefore, for low values on v, neither a tax nor a subsidy should be applied. For high v-values and high n-values, the tax should be used alone. This is due to the fact that the distortion due to pollution is then very significant compared to the distortion due to imperfect competition in the eco-industry[5]. In other words, the second distortion can be neglected, and using a tax only is better than using two costly instruments. In contrast, when the distortion due to imperfect competition is significant compared to pollution (i.e. when n and v are rather small), then a subsidy should be used as a complement to the

[5]When n, the number of firms in the eco-industry, is high we are close to perfect competition in the eco-industry and the distortion due to imperfect competition is small.

tax in order to correct that distortion. Last, the area where the combination is preferred to the tax decreases as λ increases as the use of two instruments then becomes even more costly compared to a one-instrument policy.

7 Conclusion

This paper investigates the combination of an emission tax and an environmental subsidy when abatement goods and services are supplied by an imperfectly competitive eco-industry. In the literature in environmental economics, the subsidy traditionally goes to the polluters' abatement effort. We show that such a policy is not implementable in the presence of an oligopolistic environment industry. We also show that this result remains valid with free-entry in the eco-industry. We then show that the environment firms only (not the polluters) should be subsidized. Furthermore, the regulator may want to suppress such subsidies altogether if the imperfect competition distortion is small compared to the pollution distortion and when public transfers are subject to strong distortions.

The idea of subsidizing the environment may end up being further qualified after one considers general equilibrium effects (Parry 1997) or international trade agreements. The basic conclusion would seem to hold, however, under more realistic structures for the environment industry, such as free entry or monopolistic competition. Precise conclusions, of course, will require additional research.

8 Appendix

8.1 Robustness of Proposition 1 with free entry

Let us assume there is free entry in the eco-industry and the eco-industry's activities induce a fixed cost F. The profit of a firm in the environment industry is now:

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

The first-order condition for profit maximization is:

$$q(a) = G' + \frac{a}{n}(-\frac{1}{a'}) \tag{15}$$

where $a' = \frac{\partial a}{\partial q} < 0$. The number of firms in the eco-industry is given 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 the polluters, the profit of a representative polluter is written:

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

which yields the following first-order conditions for profit maximization:

$$\begin{aligned} P - C'(x) - tw'(x) &= 0 \\ -q + t\epsilon'(a) + s &= 0 \end{aligned} \tag{16}$$

In order to reach the first-best, the regulator would then have to set: $t = v$ and $s = q - G'$. In this case we have that:

$$\frac{ds}{dq} = 1$$

in other terms, a' tends towards zero (a' is obtained by differentiating totally equation (16)). Furthermore, having $s = q - G'$ is equivalent to $s = \frac{a}{n}(-\frac{1}{a'})$ (due to equation (15)). With a' tending towards zero, we would have that s tends towards infinity. We then obtain the same result with free-entry as when the number of firms in the eco-industry is given.

8.2 Social welfare with a tax alone:

Given the functions of the model, the polluting firm's output and abatement demand when facing a tax t are respectively:

$$x^t = \frac{10 - t}{2}$$

$$a^t = (\frac{t}{2q})^2$$

$a'_t = \frac{\partial a^t}{\partial q}$ can then be written as:

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

Given the above expressions, the price for the environmental good that results from abatement demand from the polluting firm and supply from the eco-industry is:

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

Abatement demand at the equilibrium is then:

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

The social welfare is written:

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

Maximizing the above function given the above expressions for x^t and a^t and under the condition that $t > 0$ yields the following expression for the optimal tax rate:

$$t^*(\lambda) = \frac{8(v-5\lambda)n^2 - 2vn}{8n^2(1-2\lambda) - 4n(1-\lambda) + 1}$$

if this expression is positive. Else, $t^*(\lambda) = 0$.

8.3 Social welfare with the combination of instruments:

We now study social welfare when combining a tax on emissions and a subsidy on the eco-industry's output. The polluting firm's decisions are:

$$x^{st} = \frac{10-t}{2}$$

$$a^{st} = (\frac{t}{2q})^2$$

and:

$$a'_{st} = -\frac{t^2}{2q^3}$$

Given the above expressions and the behavior of the eco-industry when facing a subsidy (given by equation (12)), the equilibrium price for the environmental good is:

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

Abatement demand at the equilibrium is then:

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

The social welfare is written:

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

Maximizing the above expression under s and t, given the above expressions for x^{ts} and a^{ts}, yields the following two-equation system:

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

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

Solving this system yields:

$$s^*(\lambda) = \frac{8\lambda(3v+5\lambda-10)n^2 + (20\lambda^2+40\lambda-10\lambda v-4v)n + \lambda v}{4(30\lambda^2+\lambda v-2v)n^2 + 2\lambda(v-10\lambda)n} \qquad (17)$$

if this expression is positive. Else, $s^*(\lambda) = 0$. And:

$$t_s^*(\lambda) = \frac{n^2(160\lambda(1+\lambda) - 8v(5\lambda+2)) + 4\lambda vn}{4n^2(17\lambda^2+4\lambda-4) - 12\lambda^2 n + \lambda^2} \qquad (18)$$

if this expression is positive. Else, $t_s^*(\lambda) = 0$.

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