Voluntary Environmental Agreements, Emission Taxes and International Trade: The Importance of the Timing of Strategies

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Abstract

The purpose of the paper is to narrow the gap between the widespread use of voluntary agreements and research on the rationale of such approaches. A topical example are voluntary agreements of many industries to reduce carbon dioxide emissions because of global warming. If the industry anticipates that taxes and fees will be introduced in the coming years, it seems rational to act in advance in order to mitigate the tax levels.

The conventional approach in strategic trade and tax models was to look at a two-stage game where governments set taxes first and then firms react. In such a policy regime the government is concerned about the international competitiveness of its firms and sets taxes below marginal damages. In this paper, we consider a policy regime with a reversed timing. Firms commit themselves in the face of emission taxes to abatement efforts and to lower levels of the environmentally intensive output. Then the government introduces the tax. Under this timing of strategies the tax is equal to marginal damage. Firms waive profit and reduce output in order to use less of the polluting input. The reward for this behavior will be a less strict use of policy instruments and hence lower abatement costs in the near future.

Keywords: Environmental policy, strategic trade policy, emission taxes, voluntary agreements

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1. Introduction*

Some environmentalists express concern that in the presence of international trade and globalization, governments may relax their environmental policies to give their domestic producers a competitive advantage in international markets. Support for such concern was given by models of strategic environmental policy and international trade which showed rent-shifting incentives for governments to relax environmental policies. The focus of these studies is the effect of government policy on international strategic interaction pioneered by Brander and Spencer (1985) and modified by Barrett (1994), Conrad (1993, 1996), Kennedy (1994) and Ulph (1992) to take account of environmental pollution. While these studies appear to rationalize environmental policies, there are also studies which come to an opposite conclusion or provide reasons why the incentives for government to relax environmental policy are low. This is the case for price-instead of quantity-competition (Barrett (1994)), general equilibrium effects in factor markets (Rauscher (1994)), or both governments and producers acting strategically (Ulph (1996)).

The model of the firm and government behavior in all papers is based on a two- or three- stage game played by a number of firms, located in different countries, and by two rent-shifting governments. In the first stage, governments choose their environmental policy instruments to regulate environmental quality. In the second stage, firms decide on the level of abatement activities and choose output levels. The second-stage equilibrium is a Nash equilibrium in outputs, taking emission tax rates as given by the preceding stage. Such a timing leads to eco-dumping because the results recommend that environmental policy instruments be adjusted downward in order to prevent declining domestic output and increasing profits of the competing country. However, as pointed out by Carmichael (1987) and Gruenspecht (1988) in the context of export subsidies and international competition, the timing of actions may well be crucial. They consider trade policy models, such as Brander and Spencer (1985), in which firms set their prices first and then governments set subsidies. Their

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results underline the importance of timing and the distinction between the effects of policy regimes and of policy instruments. We will therefore reverse the timing in our model (Conrad (1993)) in order to reconsider the incentive for eco-dumping. We use a timing structure in which output and abatement decisions precede the setting of environmental policy instruments. Such a timing allows firms to recognize the impact of their decisions on the level of the tax chosen by the government. If firms anticipate the introduction of emission taxes they might produce less of the polluting good and engage more in abatement activities than if taxes were set before private competition occurs. If this environmental consense emerges from our model we consider this phenomenon as a voluntary approach. Voluntary agreements in the field of environmental policy have become a wide-spread approach to which firms adhere individually and on a non-mandatory basis. With the time structure of our two-stage decision model it is possible to provide a rationale for such a firm policy in the face of emission taxes.

With the use of more than 300 voluntary approaches across the European Union, this instrument has become a new environmental policy option. A topical example is the voluntary agreements of many industries to reduce carbon dioxide emissions because of global warming. Other examples are voluntary agreements by the motor vehicle industry to take care of an environmentally appropriate disposal of used cars or to produce a five, or even three, liter car. Voluntary agreements vary from one institutional context to the other. EU member states mainly use voluntary agreements that are negotiated between an industry organization and public authorities. As an introduction of environmental taxes or their extension to waste, water or other pollutants is still discussed, voluntary agreements are linked to other policy instruments and to many environmental problems. The re-acceptance of packing material by the seller is another example. However, compared to the widespread use of voluntary agreements, research remains relatively underdeveloped. Handbooks surveying the state of the art, pass over in silence the field of voluntary approaches. This is in sharp contrast with, for instance, environmental taxes and tradable permits. To our knowledge, the only economic analysis of the use of this new policy instrument is by Segerson and Miceli (1998). In their article, the important question is addressed of how the level of abatement under a voluntary approach is likely to compare to the first best level or the level that might have been imposed mandatorily. The authors use a threat model (in combination with a subsidy) to determine whether voluntary agreements are likely to lead to efficient environmental protection. The conclusion from their model are similar to ours. Their model is based, however, on bargaining power between the firm and the regulator and on the role of legislative threats, whereas our model is in the spirit of strategic environmental policy in the face of market share rivalry.

The structure of the paper is as follows. In the next section we set out the structure of the model. In section 3 we compare the outcome of a two-stage game under different timing structures. We distinguish different institutional settings in terms of cooperate and of non-cooperate emission taxing. In section 4 we set up a three-stage game where the engineers decide on the degree of abatement, then the governments decide on the tax levels, and finally firms compete in quantities. Whereas in these sections an emission tax is the policy instrument, in section 5 the government sets a standard. In section 6 we offer some conclusions.

2. The Basic Model

We begin with a model in which firms compete in a third market and governments choose emission taxes to maximize national welfare. A third market model is one in which one or more firms from a domestic country and one or more firms from a foreign country compete only in a third market. These firms therefore produce only for export. Lower case letters denote the domestic variables and capital letters the foreign variables. The domestic firm produces output x at cost $c(x, q(a,t))$, where $q(\cdot)$ is the price of the polluting input.[1] It consists of the basic price q_0, the cost of abatement *ca*, and the costs from taxing non-abated emissions:

(1) $$q(a,t) = q_0 + ca \cdot a \cdot e + t(1-a)e\,.$$

$ca = ca(a)$ is the unit cost of abatement which depends on the degree of abatement activity a $(0 < a < 1)$, e is an emission coefficient of the input (e.g., tons of SO_2 per ton of input), and t is an emission tax rate. We assume $ca_a > 0$ and $ca_{aa} > 0$ (using subscripts to denote derivatives). With r for revenue, the domestic firm maximizes profit π:

(2) $$\max_{x,a} \quad \pi(x, X; t) = r(x, X) - c(x, q(a,t))\,.$$

Similarly, the foreign firm maximizes profit Π:

$$(3) \qquad \max_{X,A} \quad \Pi(x,X;T) = R(x,X) - C\big(X,Q(A,T)\big),$$

where Q is similar as q in (1).[2]

The governments wish to maximize profit of its national firm less damage from global emissions plus the revenue from the emission tax. A global pollutant implies that non-abated foreign emissions also have an impact on national damage. It is $d(P)$ the convex damage function from total pollution $P = (1-a)e \cdot v + (1-A)e \cdot V$, where v and V are the quantities of the pollution intensive inputs which can be derived from Shephard's Lemma, i.e. $c_q(x,q) = v$ and $C_Q(X,Q) = V$. The objective of the domestic government is:

$$(4) \qquad \max_{t} \quad w(t;T) = r(x,X) - c(x,q(a,t)) + t \cdot (1-a)e \cdot v - d(P).$$

Similarly, the objective function of the foreign government is

$$(5) \qquad \max_{T} \quad W(T;t) = R(x,X) - C(X,Q(A,T)) + T \cdot (1-A)e \cdot V - D(P).$$

3. The Timing of Actions in Case of a Tax

In all strategic trade models with environmental background, taxes are set before private competition occurs. In these two-stage games of complete but imperfect information simultaneous moves within each stage occur. In stage one, the domestic and foreign government simultaneously set tax rates t and T. In the second stage, firms observe the outcome of the first stage, t and T, and then simultaneously choose x and X and decide on abatement efforts. The payoffs are $\pi(x,X,t,T)$ and $w(x,X,t,T)$ $(\Pi, W$ respectively).[3] The first step in solving the game by backwards induction is to solve the game between the two firms. We will denote the unique Nash equilibrium (which we assume to exist) by $x = \hat{x}(t,T)$ and $X = \hat{X}(t,T)$. The abatement efforts are $\hat{a}(t)$ and $\hat{A}(T)$. Now the first-stage interaction of the two governments amounts to simultaneously choosing t and T. The payoffs for the domestic country are $\pi\big(\hat{x}(t,T), \hat{X}(t,T), t, T, \hat{a}(t), \hat{A}(T)\big)$ and $w(\cdot)$. The sub-game-perfect

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[1] All other input prices are constant and have been omitted as arguments in the cost function.
[2] The emission coefficient e is assumed to be the same in the two countries.
[3] These two-stage games are standard textbook material, see Gibbons (1992).

outcome of this two-stage game is $\pi\left(\hat{x}(\hat{t},\hat{T}),\hat{X}(\hat{t},\hat{T}),\hat{t},\hat{T},\hat{a}(\hat{t}),\hat{A}(\hat{T})\right)$ etc. with $\hat{t},\hat{T}$ as the Nash equilibrium of the first stage. The conclusion from this model was denoted as eco-dumping (Rauscher (1994)); the emission taxes turned out to be lower than marginal damage:

(6) $$\hat{t} < md\left(\hat{P}\right) \quad , \quad \hat{T} < MD\left(\hat{P}\right)$$

where $\hat{P} = \left((1-\hat{a})e\,\hat{v} + \left(1-\hat{A}\right)e \cdot \hat{V}\right)$. The Pigouvian tax, i.e., marginal damage value, should be adjusted downward to keep a greater share of the output of rent-earning domestic industries. A high tax rate depresses domestic output and increases revenue of the competing country.

In order to determine the degree of abatement, a, we maximize (2) with respect to *a* which is equivalent to $\min_a \quad q(a;t)$. The FOC is

(7) $$\frac{dq}{da} = \left(ca_a \cdot a + ca - t\right) \cdot e = 0;$$

i.e., the marginal cost of abatement is equal to the tax rate. (Similarly for the foreign firm). We observe that the degree *a* is only a function of t and independent from *x* or *X*. Reaction functions *a(A)* and *A(a)* are rectangular to the axes and there is no game in the degrees of abatement. We assume that *a* and *A* are chosen prior to production.

As in any economic policy, also in environmental policy can the timing and the distinction between the effects of policy regimes and policy instruments be important. The world-wide use of voluntary approaches is evidence that firms appear to choose quantities and degrees of abatement prior to the setting of emission taxes by the government. This motivates to consider models in which quantities and degrees of abatement are set before governments choose emission tax levels. Firms can affect tax levels via their output levels and abatement policies. Tax programs are likely to be established only when there is a coincidence of government interest and private consense. To obtain a sub-game-perfect outcome, firms now move first and compete in output levels and abatement efforts. In the second stage, governments observe the outcome of the first stage, *x*, *X*, *a* and *A*, and set environmental tax rates. This time the first step in solving the game by backwards induction is to solve the game between the two governments. The Nash equilibrium is $t^*(x,X,a,A)$ and $T^*(x,X,a,A)$. The first-stage interaction of the two firms amounts in simultaneously choosing *x* and *X*, and in deciding on abatement efforts. The sub-game-perfect outcome of this two-stage game is

$$\pi\left(x^*, X^*, t^*(x^*, X^*, a^*, A^*), T^*(x^*, X^*, a^*, A^*), a^*, A^*\right)$$

and similarly for *w* with x^*, X^* as the Nash equilibrium of the first stage.

The FOC from maximizing the objective function (4) by the domestic government is:

$$w_t = -c_q\, q_t + (1-a)e \cdot v + t(1-a)e\, v_q\, q_t - md \cdot (1-a)e\, v_q\, q_t = 0\,.$$

The government considers the outputs *x* and *X* as well as the degree of abatements *a* and *A* as fixed, but can use the tax to accomplish production processes which use less of the emission intensive input $v = v(x, q(t))$. Using Shephard`s Lemma $\left(c_q = v\right)$ and $q_t = (1-a)e$ yields

(8) $$t = md\left(P(x, X, a, A, t; T)\right)$$

with $P(\cdot) = (1-a)e \cdot v\left(x, q(a,t)\right) + (1-A)e \cdot V\left(X, Q(A,T)\right)$. Similarly, the FOC for the foreign government is:

(9) $$T = MD\left(P(x, X, a, A, T; t)\right)$$

with $P(\cdot)$ as in (8). The solutions to (8) and (9) depend on domestic and foreign output levels and degrees of abatement. They can be written as

(10) $$t = t^*(x, X, a, A) \qquad , \qquad T = T^*(x, X, a, A)\,.$$

Output affects the derived demands $v(x)$ and $V(X)$ for the polluting input, the cause of environmental damage, and hence the emission taxes.

The firms anticipate the effect of their output levels and abatement efforts on the tax rates. The direction of this effect follows from total differentiation of *t* and *T* in (8) and (9) with respect to x, X, a and *A*:[4]

(11) $$\frac{dt}{da} = \frac{d''(P)}{\Omega}\left(-v + (1-a)v_q\, q_a\right) < 0$$

[4] For a proof see the Appendix.

as $v_q < 0$, $q_a > 0$ and $d''(P) > 0$ by assumption. Since $\Omega = w_{tt}\ W_{TT} - w_{tT}\ W_{Tt} > 0$, uniqueness and global stability of the equilibrium is ensured. Similarly, we can show:

(12) $$\frac{dt}{dx} = \frac{d''(P)}{\Omega}(1-a)v_x > 0$$

as $v_x > 0$. If marginal damage increases sharply and firms would voluntarily raise the degree of abatement and reduce output, they could expect lower taxes in the second stage. Similar expressions can be derived for $\frac{dt}{dA} < 0$ and $\frac{dt}{dX} > 0$.

If in the first stage of the game, the firms change *x* or *X*, and *a* or *A*, then the reaction functions $t = \psi(T; x, X, a, A)$ and $T = \Psi\,(t; x, X, a, A)$, derived from (8) and (9), will shift and the tax rates will change. If the domestic or foreign firm raises its output level, then the domestic (and foreign) government will set a higher emission tax. If the firms choose (voluntarily) a higher degree of abatement, then the government will set lower emission taxes. A government's Nash equilibrium level of taxes is increasing in output levels and decreasing in abatement efforts.

If the firms anticipate that the second-stage behavior of the two governments will be given by (10), then the first-stage interaction follows from choosing *x* and *X* such that (2) and (3) will be maximized:

(2') $$\max_{x,a} \quad \pi\left(x, X; t^*(x, X, a, A)\right)$$

(3') $$\max_{X,A} \quad \Pi\left(x, X; T^*(x, X, a, A)\right).$$

The FOCs are

$$\pi_x = r_x - c_x - c_q \cdot q_t \frac{\partial t}{\partial x} = 0$$

or

(13) $$r_x - c_x - v(1-a)\,e\,\frac{\partial t}{\partial x} = 0$$

and

(14) $$R_X - C_X - V\,(1-A)\,e\,\frac{\partial T}{\partial X} = 0.$$

As the tax will increase with higher production of the pollution intensive good (see (12)), firms act strategically by producing a lower output x^* than in the case of reverse timing. In the latter case, the solution $\hat{x}$ comes from $r_x - c_x = 0$, hence $\hat{x} > x^*$. Under voluntary agreements in the face of an emission tax, the firms will produce less than in a policy regime where governments anticipate the second-stage behavior of the firms.

The FOC with respect to *a* is

$$\pi_a = -c_q \left(q_a + q_t \frac{\partial t}{\partial a} \right) = 0$$

or

(15) $$(ca' \cdot a + ca - t) + (1-a) \frac{\partial t}{\partial a} = 0$$

(Similarly for *A*). As the tax will be lower if a higher degree of abatement is chosen by the firm (see (11)), a^* will be set higher than $\hat{a}$ from (7), obtained under the reverse policy regime.

Under the reverse policy, $\hat{t}$ was below its marginal damage $md(\hat{x}, \hat{X}, \hat{a}, \hat{A})$ due to rent - shifting considerations by the two governments. In the policy regime under consideration, t^* is also below $md(\hat{x}, \hat{X}, \hat{a}, \hat{A})$ because $x^* < \hat{x},\ a^* > \hat{a},\ X^* < \hat{X}$ and $A^* > \hat{A}$. However, the taxes are equal to the Pigouvian tax:

$$t^* = md(x^*, X^*, a^*, A^*)$$
$$T^* = MD(x^*, X^*, a^*, A^*)$$

Although voluntary approaches widely vary from one institutional context to the other, they all have in common to mitigate the environmental tax policy. Firms cooperate by announcing or choosing high degrees of abatement and reduced production levels, knowing that the renounced profit will be compensated by lower taxes in the tax stage.

We finally discuss the cooperative equilibrium if both governments jointly maximize international (two – country) welfare. In this case they maximize

(16) $$\max_{t,T} \ TW(t,T) = w(t;T) + W(T;t)$$

with $w(t;T)$ and $W(T;t)$ as defined in (4) and (5). If governments move first in choosing tax rates, anticipating firms reaction on the tax levels, the simultaneous solution of the two FOCs is:[5]

$$\hat{t}_{coop} = md + MD - \frac{R_x}{(1-a)\cdot e \cdot v_x}$$

$$\hat{T}_{coop} = md + MD - \frac{r_X}{(1-A)\cdot e \cdot V_X}$$

Because of $R_x < 0,\ r_X < 0$, cooperative tax rates should be even higher than the sum of the marginal damages in both countries. Since national production exerts a negative externality on the other country's revenue, a cooperative agreement takes this aspect into account.

If we reverse the timing and the government maximize (16) in the second stage of the game, then we obtain from solving the FOCs:

$$t^*_{coop} = T^*_{coop} = md + MD.$$

Tax rates should be equal to the sum of marginal damages and should be the same for both countries. Total differentiation of these FOCs yields:[6]

$$\frac{d\,t^*_{coop}}{d\,a} < \frac{d\,t^*_{Nash}}{d\,a} < 0\,.$$

If the firms choose voluntarily a higher degree of abatement at the first stage of the game, then the governments response at the second stage with a higher tax reduction when there is cooperation in environmental policy. Similarly, it can be shown that the following inequality holds:

$$\frac{d\,t^*_{coop}}{d\,x} > \frac{d\,t^*_{Nash}}{d\,x} > 0\,.$$

[5] See Conrad (1993)
[6] For a proof see the Appendix

A commitment to reduce output and hence the use of polluting inputs will be rewarded by a higher tax cut if government cooperate at the second stage. Again, if the firms anticipate the behavior of the cooperating governments, they will produce less than $\hat{x}$, according to (13), and will choose a higher degree of abatement, according to (15).

4. The Timing of Actions: Abatement, then Taxes, and then Output

Most of the strategic models are set up as three-stage games. At the policy stage governments set, say, taxes. At the technological stage firms choose R&D or abatement efforts, and at the third, the market stage, price or quantity competition takes place. In this section, we begin with the technological stage because an irreversible action could be a strategic advantage for the firm when tax rates are chosen by the governments. The three stages are as follows:

Stage one: The engineering department decides on the degree of abatement by anticipating that the level of a tax rate on emissions will depend on the observed abatement behavior of firms.

Stage two: The governments observe the abatement behavior and decide on emission taxes, being aware that the level of those taxes will influence the international competitiveness of their firms.

Stage three: Firms compete in quantities, given the degree of abatement chosen by their engineering departments, and the tax levels set by their governments.

We solve by backward induction, i.e. by solving the 3. stage, given *a*, *A*, *t* and *T*. From the FOCs $r_x = c_x$ and $R_X = C_X$ we obtain by total differentiation (Conrad (1993)):

(17) $$\frac{dx}{dt} < 0 \quad , \quad \frac{dx}{dT} > 0 \quad , \quad \frac{dX}{dt} > 0 \quad , \quad \frac{dX}{dT} < 0 .$$

The Nash-solution of the game is $x^*(t,T)$ and $X^*(t,T)$. Next, we solve the second stage:

$$\max_t \quad \pi(x(t,T), X(t,T), t) + t(1-a)\, e \cdot v - d(P) .$$

The FOC is

$$\pi_x \frac{dx}{dt} + \Pi_X \frac{dX}{dt} - c_q \frac{dq}{dt} + (1-a)\, e \cdot v + t(1-a)\, e \cdot \left[v_x \frac{dx}{dt} + v_q \frac{dq}{dt} \right]$$
$$- md \cdot \left[(1-a)\, e \left(v_x \frac{dx}{dt} + v_q \frac{dq}{dt} \right) + (1-A)\, e \cdot V_X \frac{dX}{dt} \right] = 0 \quad .$$

Using $\pi_x = 0$ from the behavior of the firm, $c_q = v$ (Shephard's lemma), and $\frac{dq}{dt} = (1-a)\, e$, we obtain

(18)
$$t = md + \frac{-\overset{(-)}{r_X} \frac{d\overset{(+)}{X}}{dt} + md \cdot (1-A)\, e \cdot V_X \frac{d\overset{(+)}{X}}{dt}}{(1-a)\, e \left[\underset{(-)}{v_x \frac{dx}{dt}} + \underset{(-)}{v_q (1-a)\, e} \right]} \quad .$$

The numerator is positive and the denominator is negative. It is $t < md$, the tax policy for eco-dumping as derived in Conrad (1993). Eq. (18) is an implicit reaction function $t = t(T; a, A)$. In a similar way, $T = T(t; a, A)$ can be derived. The Nash-equilibrium in the tax rates is $t^* = t(a, A)$ and $T^* = T(a, A)$.

In order to know how the degrees of abatement, *a* and *A*, will shift the tax reaction functions of the government, we have to determine the signs of dt/da or dt/dA. Unfortunately, total differentiation of (18) and of the equivalent equation for *T* is a terrible task. We tried it but dropped the fraction in (18). Then, the system for total differentiation of *t* and *T* with respect to *a* and *A* is:

(19)
$$t - md((1-a)\, e \cdot v(x(t,T), q(a,t)) + (1-A)\, e \cdot V(X(t,T), Q(A,T))) = 0$$
$$T - MD((1-a)\, e \cdot v(x(t,T), q(a,t)) + (1-A)\, e \cdot V(X(t,T), Q(A,T))) = 0 \quad .$$

We obtain

(20)
$$\frac{dt}{da} = \frac{d''}{\Gamma} \left[(-e \cdot v + (1-a)e \cdot v_q q_a)\, (1 - (1-A)e \cdot V_Q\, Q_T \cdot D'') \right]$$

where $\Gamma > 0$ is the determinate of the two-equation system in *dt* and *dT*, derived from (19). Since $v_q < 0$, $V_Q < 0$, it is

(21) $$\frac{dt}{da} < 0.$$

The first term in the brackets in (20) represents the effect of a higher degree of abatement on less emissions form reducing the input $(-e \cdot v)$ and from substitution $((1-a)e \cdot v_q\, q_a)$. The second term represents the foreign country effect on the domestic government response to a higher degree *a*. If no substitutes are available in the foreign country $(V_Q = 0)$, then the domestic firm anticipates that the tax rate *t* will be lowered by a smaller rate in response to a higher degree *a* than if substitutes are available $(V_Q < 0)$. In a similar way, $dt/dA < 0$ can be proven.

Finally, we solve the first stage, the problem of the engineering department to choose an environmentally friendly production process. Equivalent to $\max_a \pi$ is $\min_a c(x, q[a, t(a, A)])$; the FOC is $c_q \cdot q_a = 0$ or

(22) $$ca' \cdot a + ca - t + (1-a)\frac{\partial t}{\partial a} = 0.$$

We can conclude from (21) that the engineering department will choose a higher degree a^* than in the case of reverse timing (i.e. $\hat{a}$). As $t = t^*(a, A)$, the FOC (22) is an implicit reaction function $a = a^*(A)$. By totally differentiating (22), we obtain a negatively sloped reaction function $da/dA < 0$; the degrees of abatement are strategic substitutes. If the foreign engineering department chooses a high degree of abatement, this will improve the environment, and marginal damage, i.e. the domestic tax *t*, will turn out to be lower. It then minimizes costs to lower the abatement effort, i.e. *a*. We finally summarize our game in a figure:

$$\begin{tikzcd}
\text{1. stage:} & a^* \arrow[r, leftrightarrow] \arrow[d] \arrow[dr] & A^* \arrow[d] \arrow[dl] & \text{engineers} \\
\text{2. stage:} & t = t^*(a,A) \arrow[d] \arrow[dr] & T = T^*(a,A) \arrow[d] \arrow[dl] & \text{governments} \\
\text{3. stage} & x = x^*(t,T) & X = X^*(t,T) & \text{firms}
\end{tikzcd}$$

In terms of our interpretation of voluntary agreements, firms anticipate that the level of the coming emission tax will depend on the abatement efforts shown prior to the introduction of a tax. They bear higher costs of abatement at the first stage in order to save tax expenditure at the second stage. If the firms would produce the same output levels $\hat{x}$ and $\hat{X}$, obtained under eco-dumping, it is obvious that the tax rates under voluntary agreements will be lower, i.e. $t^*(a^*, A^*; \hat{x}, \hat{X}) < \hat{t}(\hat{a}, \hat{A}, \hat{x}, \hat{X})$, because formula (18) for the tax rate t is the same under either timing. With lower taxes t^* and T^* at the third stage, the profit maximizing output levels $x^*$and X^* will be higher than $\hat{x}$ and $\hat{X}$ (same condition $r_x = c_x$ in either cases). Therefore, also the increase in profit from higher output compensates for the higher abatement costs in the first stage. Since $(x^*, X^*) > (\hat{x}, \hat{X})$ must hold, this implies $q^* < \hat{q}$, i.e. the cost increasing effect of $a^* > \hat{a}$ must be lower than the cost raising effect of t^*.[7]

5. The Timing of Actions in Case of a Standard

In this section, we assume that the behavior of the governments is characterized by a game in the degrees of abatement. In that case, the domestic government maximizes at the second stage of the game the welfare function

$$\max_a \quad w(a, A) = r(x, X) - c\big(x, q(a)\big) - d(P).$$

The FOC is

$$w_a = -v \cdot q_a - md(P) \cdot \big[-v \cdot e + (1-a)e \cdot v_q \; q_a\big] = 0 \tag{23}$$

[7] $t^* < \hat{t}$ is a sufficient, but not a necessary condition for $q^* < \hat{q}$.

or, casted in terms of elasticities,

(24) $$md(P)\left[1+\frac{(1-a)}{a}\left|\varepsilon_{v,q}\right|\cdot\varepsilon_{q,a}\right]=ca'\cdot a+a$$

where $q_a = e\cdot(ca'\cdot a + ca) > 0$ and $\varepsilon_{q,a}$ is the elasticity of the input price with respect to *a*. If the elasticity of demand for the pollution intensive input, $\varepsilon_{v,q}$, is zero, then the degree of abatement should be chosen such that marginal cost of abatement is equal to marginal damage. If substitution away from the input is possible, then the term in the brackets is greater than one, and this implies a higher standard, *a*, as a hint to make use of the substitution possibilities. The reason for this adjustment of *a* is that our standard applies to reductions in pollution per unit of the polluting input and does not allow for abatement by substitution between inputs (for example, low sulfur coal for high sulfur coal). This is why, when no substitutes are available $\left(\varepsilon_{v,q}=0\right)$, *md* is equal to $ca'\cdot a+a$.[8]

The condition (23) is an implicit reaction function of the domestic government because *P* depends on *A*. Furthermore, *v* depends on *x*, and *V* on *X* i.e. $a = r(A; x, X)$. Total differentiation of (23) and of the corresponding condition $W_A = 0$ for the foreign government shows[9] that the Nash equilibrium in the degrees of abatement are increasing in the firms output levels,

(25) $$\frac{d\,a}{d\,x}>0 \qquad , \qquad \frac{d\,A}{d\,X}>0.$$

If the firm anticipates that the standard setting policy of the governments will be given by

$$a = a^{**}(x, X) \qquad , \qquad A = A^{**}(x, X)$$

[8] An alternative formulation of introducing a standard could be

$$\max_a \quad w(a,A) = r(x,X) - c(x,q(a)) \qquad s.t. \quad (1-a)e\cdot v + (1-A)e\cdot V = \overline{P}$$

where $\overline{P}$ is total emission permitted. The FOC is identical to (23) except that a Lagrange variable, the shadow cost of emission, replaces *md*.

[9] For a proof see the Appendix

then the quantity game follows from maximizing (2) and (3), but now only with respect to *x* and *X*. The FOC for the domestic firm is

$$\pi_x = r_x - c_x - v \cdot q_a \frac{\partial a}{\partial x} = 0$$

and similarly for the foreign firm. Again, the anticipated effect of *x* on *a* will shift the reaction functions in an $x - X$ diagram downward and the Nash-equilibrium levels of output will be lower. Due to the expected stricter regulation under high levels of the pollution intensive output, the firms will voluntarily decide to reduce outputs x^{**} and X^{**}. They waive profit by restricting output in order to save costs when the governments introduce the standards.

We conclude that in case there are no substitutes for the polluting input, then the standards $a^{**}\left(x^{**}, X^{**}\right)$ and $A^{**}\left(x^{**}, X^{**}\right)$ will be less strict since the value of $md\left(x^{**}, X^{**}\right)$ will be lower than $md(\hat{x}, \hat{X})$. If substitution possibilities exist, the standards could be stricter at the second-stage due to its inflexibility in being fixed to $a \cdot 100$ percent of a certain input. However, voluntary agreements by the firms to produce less will weaken these standards.

5. Summary and Conclusion

Voluntary approaches in the field of environmental policy have now become popular worldwide. If the industry anticipates that taxes and fees will be introduced in the coming years, it seems rational to act in advance in order to mitigate the necessity for taxes. When the new coalition of social democrats and the green party announced to introduce an energy tax in Germany in 1999, representatives of the industry pointed out to the government that the industry has voluntarily committed to reduce carbon dioxide emission but the now coming energy tax will take away the base for its agreement; i.e. the industry expected an even lower tax rate or no tax at all. Since energy-intensive industries will be exempted from the energy tax, the voluntary approach was nevertheless successful.

To explain strategic behavior, the conventional approach in environmental economics was to look at a two-stage game where governments set taxes first and then firms react. In such a policy regime the government is concerned about the international competitiveness of its firms and sets taxes below marginal damage or prefers weaker standards. In this paper, we considered a policy regime with a reversed timing. Firms commit themselves in the face of emission taxes to abatement efforts and to lower levels of the environmentally intensive output. Then the government introduces the tax. Our model can be interpreted as the theoretical underpinning of voluntary agreements. Under either standards or taxes, they waive profit and reduce output in order to use less of the polluting input. The reward for this behavior will be less strict policy instruments and hence lower abatement costs in the near future. We hope that our analysis can close somewhat the gap between the widespread use of voluntary approaches and the relatively underdeveloped research in this area.

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Appendix

Proof of (11) and (12)

Total differentiation of (8) and (9) with respect to *t*, *T*, *a* and *x* yields:

$$dt\left(1-d''\cdot(1-a)\,v_q q_t\right)-\left(d''\cdot(1-A)\,V_Q Q_T\right)dT = \\ d''\cdot\left[-v+(1-a)\,v_q q_a\right]da + d''\cdot(1-a)\,v_x dx$$

and

$$dT\left(1-D''\cdot(1-A)\,V_Q Q_T\right)-\left(D''(1-a)\,v_q q_t\right)dt = \\ D''\cdot\left[-v+(1-a)v_q q_a\right]da + D''(1-a)\,v_x dx$$

In a more compact way:

$$w_{tt}\quad dt + w_{tT}\ dT = -w_{t,a}da - w_{t,x}dx \\ W_{T,t}\quad dt + W_{TT}\ dT = -W_{T,a}da - W_{T,x}dx$$

The determinant Ω is positive, i.e. $\Omega = w_{tt}W_{TT} + w_{tT}\cdot W_{T,t} > 0.$ We set $dx = 0$ and use Cramer`s rule:

$$\Omega\quad \frac{dt}{da} = -w_{t,a}\cdot W_{TT} + W_{T,a}\cdot w_{tT}$$

In the terms derived above:

$$\Omega\quad \frac{dt}{da} = d''\cdot\left[-v+\left(1-a\right)v_q q_a\right]\left(1-D''\left(1-A\right)V_Q Q_T\right) \\ +D''\left[-v+\left(1-a\right)v_q q_a\right]d''\left(1-A\right)V_Q Q_T$$

This can be rewritten as

$$\Omega \quad \frac{dt}{da} = d'' \cdot \left(-v + \left(1-a\right) v_q q_a\right)\left(1 - D''\left(1-A\right) V_Q Q_T + D''\left(1-A\right) V_Q Q_T\right)$$

which proves (11).

Similarly,

$$\Omega \quad \frac{dt}{dx} = -w_{t,x} \cdot W_{TT} + W_{T,x} \cdot w_{tT} = d''(1-a)\, v_x\left(1 - D''(1-A)\, V_Q Q_T\right)$$
$$+D''(1-a)\, v_x \cdot d''(1-A)\, V_Q Q_T = d''(1-a)\, v_x\left[1 - D''(1-A)\, V_Q Q_T + D''(1-A)\, V_Q Q_T\right]$$

which proves (12).

Proof of the cooperative tax rates and of (16)

The FOC with respect to *t* is

$$-v_{qt} + \left(1-a\right) v + t\left(1-a\right) v_q q_t - md \cdot \left(1-a\right) v_q q_t - MD \cdot \left(1-a\right) v_q q_t = 0$$

which yields $t^{coop} = md(P) + MD(P)$.

Similarly, $T^{coop} = md(P) + MD(P)$.

Total differentiation with respect to *t*, *T*, and *a*:

$$dt\left[1 - (d'' + D'')(1-a)\, v_q q_t\right] - (d'' + D'')(1-A)\, V_Q Q_T \; dT = \left(-v + (1-a)\, v_q q_a\right)(d'' + D'')\; da$$

$$dT\left[1 - (d'' + D'')(1-A)\, V_Q Q_r\right] dT - (d'' + D'')(1-a)\, v_q q_t dt = \left(-v + (1-a)\, v_q q_a\right)(d'' + D'') da\,.$$

We denote the determinant of this linear equations system by $\Omega^{coop} > 0$ and find as solution:

(A 1) $$\frac{dt^{coop}}{da} = \frac{\left(-v + (1-a)\, v_q q_a\right)(d'' + D'')}{\Omega^{coop}} < 0$$

Since $d'' + D''$ appears in the numerator, the cooperative tax rate responds more intensively to a higher degree of abatement. This statement holds only if $\Omega^{coop} < \Omega$, the determinant for the non - cooperative case. To show this inequality sign, Ω^{coop} can be written as

$$\Omega^{coop} = \frac{(d'' + D'')^2}{d''\ D''} \left[\left[\frac{d''}{d'' + D''} - d''\ v_q q_t (1-a) \right] \cdot \left[\frac{D''}{d'' + D''} - D''(1-A)\ V_Q Q_T \right] \right.$$
$$\left. + d''\ D''\ (1-a)\ v_q q_t (1-A)\ V_Q Q_T \right]$$

Because of $\frac{d''}{d'' + D''} < 1$, the expression after $\frac{(d'' + D'')^2}{d''\ D''}$ is less than Ω. If we substitute Ω^{coop} in (A 1), this lower - than - Ω - expression appears in the denominator and $\frac{d''\ D''}{d'' + D''}$ in the numerator. However, $\frac{d''\ D''}{d'' + D''}$ is less than d'' which proves that voluntarily higher degrees of abatement will result in even lower tax rates in the cooperative case compared to the non - cooperative case. In a similar way, $\frac{dt^{coop}}{dx} > \frac{dt^{Nash}}{dx} > 0$ can be shown to be true.

Proof of (19)

Total differentiation of (17) with respect to *a*, *A*, *x* and *X* yields

$$\left[-v_q q_a^2 - v\ q_{aa} - d'' \cdot \left[-v + (1-a)\ v_q q_a \right]^2 - md \cdot \left[-2 v_q q_a + (1-a) \left(v_{qq} q_a^2 + v_q \cdot q_{aa} \right) \right] \right] da$$
$$- d'' \cdot \left(-V + (1-A)\ V_Q Q_A \right) \left[-v + (1-a)\ v_q q_a \right] dA$$
$$= \left(v_x q_a + d'' \cdot (1-a)\ v_x \left[-v + (1-a)\ v_q q_a \right] + md \cdot \left(-v_x + (1-a)\ v_{qx} q_a \right) \right) dx$$
$$+ d'' \cdot (1-A)\ V_X \left[-v + (1-a)\ v_q q_a \right] dX$$

By exchanging capital and small letters, a similar equation follows from the FOC $W_A = 0.$ We set $dX = 0$ and write our inhomogeneous equation system as

$$w_{a,a} da + w_{a,A}\ dA = -w_{a,x}\ dx$$
$$W_{A,a} da + W_{AA}\ dA = -W_{A,x}\ dx$$

where $w_{a,a,}$ $w_{a,A}$ and $w_{a,x}$ have been determined above. The determinant Ω of this system is positive . Using Cramer`s rule yields:

$$\frac{da}{dx} = \left(-w_{a,x} \cdot W_{AA} + W_{A,x}\ w_{a,A}\right) / \Omega$$

or $$\Omega\,\frac{da}{dx} = v_x q_A W_{AA} + d''(1-a)\, v_x\left(-v + (1-a)\, v_q q_a\right) W_{AA} + md\left(-v_x + (1-a)\, v_{qx} q_a\right) W_{AA}$$
$$+ d''\left(-V + (1-A)\, V_Q Q_A\right)^2 \left(-v + (1-a)\, v_q q_a\right) D'' \cdot (1-a)\, v_x$$

We wish to show that this expressing is positive. We rearrange the first and third as well as the second and fourth terms:

(A2) $$\Omega\,\frac{da}{dx} = \left[v_x\left(q_A - md\right) + md(1-a)\, v_{qx} q_a\right] W_{AA}$$
$$+\ d'' \cdot (1-a)\, v_x\left(-v + (1-a)\, v_q q_a\right)\left[W_{AA} + \left(-V + (1-A) V_Q Q_A\right)^2 D''\right]$$

In the very last bracket, W_{AA} is negative but the squared term is positive. We therefore have to write W_{AA} in explicit form and then add the positive term. It turns out that this positive term cancels out with the same but negative term:

$$W_{AA} + \left(-V + (1-A)\, V_Q Q_A\right)^2 D'' =$$
$$-V_Q Q_A^2 - V \cdot Q_{AA} - \left[-V + (1-A)\, V_Q Q_A\right]^2 D'' - MD\left[-2\, V_Q Q_A + (1-A)\left(V_{QQ} Q_A^2 + V_Q Q_{AA}\right)\right]$$
$$+\left[-V + (1-A)\, V_Q \cdot Q_A\right]^2 D'' = \left[-V_Q Q_A^2 - V \cdot Q_{AA} - MD - 2\, V_Q Q_A + (1-A)\left(V_{QQ} Q_A^2 + V_Q Q_{AA}\right)\right]$$

This expression is negative if we assume $V_{AA} > 0$ (V_{AA} is the term in the very last bracket). Multiplied by a negative term in (A2) yields a positive term. Since $v_{qx} < 0$, the first term is positive if $q_A = md$. We assume that the difference is small and hence $da / dx > 0$.