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Costly Enforcement of Voluntary Environmental Agreements with Industries

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Abstract: Although the theoretical literature on the performance of voluntary approaches to environmental protection has progressed quite far in the last decade, no one has rigorously addressed the obvious point that even voluntary emissions control policies must be enforced. This paper examines the consequences of the need for costly enforcement of voluntary environmental agreements with industries on the ability of these agreements to meet regulatory objectives, the levels of industry participation with these agreements, and the relative efficiency of voluntary and regulatory approaches. We find that enforcement costs that are borne by the members of a voluntary emissions control agreement limit the circumstances under which an agreement can form in place of an emissions tax. However, if an agreement does form, member-financed enforcement induces greater participation than if compliance with the agreement could be enforced without cost to its members. Moreover, a voluntary emission control agreement with an industry can be a more efficient way to achieve an environmental quality objective than an emission tax, but only if: (1) the members of an agreement bear the costs of enforcing compliance with the agreement; (2) there exists member-financed agreements that reach the government's environmental quality target while leaving the members of the agreement at least as well off as they would be under an emissions tax, and (3) the enforcer of the agreement has a significantly better monitoring technology or a higher sanction available to it than the government.

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1. Introduction

In recent years there has been growing interest in the use of voluntary environmental agreements between regulators and polluting industries in place of standard regulatory approaches. In many of these arrangements the government agrees not to impose a costly conventional regulation on an industry provided that it can meet an environmental quality objective voluntarily. These forms of voluntary agreements are typically referred to as *negotiated agreements*, and are the most common voluntary approach used in Europe (Conrad 2001). Examples include France's Agreement on the Treatment of End-of-Life Vehicles, Germany's Agreement on Global Warming Prevention, Denmark's Agreement on Recycling of Transport Packaging and the

Dutch National Environmental Plan, among several others.[1] Voluntary agreements are thought to have a number of advantages over traditional regulation. Firms may enjoy significant cost-savings from having increased flexibility in deciding how to meet an environmental target (Baggot 1986; Goodin 1986). Furthermore, voluntary agreements may help reduce the time necessary to develop traditional forms of regulation and may reduce conflicts between regulators and firms that often occur in this process (Segerson and Miceli 1998). Finally, some authors have suggested that voluntary agreements are likely to be cheaper to enforce than traditional regulations (Bailey 1999; Schmelzer 1999; Brouhle et al. 2005; Croci 2005).

While the theoretical literature on the performance of voluntary approaches to environmental regulation has progressed quite far in the last decade, no one has rigorously addressed the obvious point that voluntary environmental agreements with industries must be enforced, either by the government, or by the industry itself. This paper examines the consequences of enforcement costs that are borne by the members of voluntary agreements on the ability of these agreements to meet regulatory objectives, the levels of voluntary participation with these agreements, the relative costs of enforcing voluntary agreements and conventional regulations, and the relative efficiency of voluntary and regulatory approaches.

Most existing theoretical analyses of voluntary agreements model simple agreements made between the government and a single firm, or a series of independent agreements with an arbitrary number of firms (Segerson and Miceli 1998; Segerson and Miceli 1999; Schmelzer 1999; Nyborg 2000; Lyon and Maxwell 2003).[2] Modeling voluntary agreements in this way

[1] For reviews of voluntary agreements in Europe and the United States see EEA (1997), Mazurek (1998), Brouhle et al. (2005), and Schnabl (2005).

[2] The main conclusion of these studies is that voluntary approaches are most likely to meet environmental targets when there is a strong background threat of costly mandatory regulation. The limited empirical evidence on voluntary agreements largely supports this claim (Davies and Mazurek 1996; Khanna and Damon 1999; Lyon and Maxwell 2002; Maxwell 2000; Maxwell, Lyon and Hackett 2000; Alberini and Segerson 2002).

precludes the important possibility that an environmental agreement with an industry may involve only a subset of firms while the remaining firms free ride. Recently, Dawson and Segerson (2007) examine the causes and consequences of this free-riding problem. In their model, a regulator offers an industry the opportunity to voluntarily meet an aggregate emissions target instead of imposing an emissions tax that would meet the target. To determine the equilibrium number of participating firms with a voluntary agreement, Dawson and Segerson use the concept of *self-enforcing agreements* that was developed to examine stable cartels (D'Aspremont et al. 1983; Diamontoudi 2005) and is used extensively in the literature on international environmental agreements (e.g., Carraro and Siniscalco 1993; Barrett 1994; Kolstad 2007). Dawson and Segerson demonstrate that voluntary agreements can meet environmental quality goals, but they will typically involve less than full participation of the firms in an industry. Because some firms free-ride on the emission control of other firms, voluntary agreements cannot be expected to distribute emission control responsibilities efficiently.

Though widely used, the term *self-enforcing agreement* is a bit misleading, because it refers to the stability of voluntary agreements, not to maintaining the compliance of the members of an agreement. Like most authors who use this equilibrium concept, Dawson and Segerson assume that once a self-enforcing agreement has formed, the members of the agreement will not violate its requirements. Building from their model, we examine a voluntary agreement made between a government and industry in which firms that join the agreement have an incentive to violate its requirements if it is not properly enforced.. To counteract this incentive, we assume that the members of an agreement not only agree to reduce their emissions so that the regulatory objective is achieved, they also finance and empower an independent enforcer to monitor their performance and to apply a sanction when it discovers a member firm has failed to meet its emissions control requirement.

Our efforts yield several new results. First, while the model of Dawson and Segerson predicts that voluntary agreements can always meet a regulatory objective in place of an emissions tax, we demonstrate that enforcement costs that are borne by the members of an agreement limit the circumstances under which voluntary emission control agreements can form. Surprisingly, however, if an agreement does form, member-financed enforcement induces greater participation than if compliance with the agreement could be enforced without cost, or if the enforcement costs are borne by the government.

We also address the claim that voluntary agreements may be cheaper to enforce than traditional regulation. Bailey (1999) speculates that this may be true, because only the subset of firms that join a voluntary agreement need to be monitored. Others predict a cost savings because of expected advantages an industry-led enforcement scheme has over government enforcement (Schmelzer 1999). For example, it is possible that an enforcer of a voluntary agreement has better information than the government about firms' incentives and could therefore monitor their compliance behavior more effectively. Additionally, industry-led enforcement may be capable of imposing higher penalties for noncompliance, for example, by revoking the membership of noncompliant firms in trade associations (Nyborg 2000).

We demonstrate that a voluntary agreement is not cheaper to enforce than an emissions tax when the enforcer of the agreement possesses the same monitoring technology and sanction as the government. Voluntary agreements are cheaper to enforce only if the enforcer of such an agreement has an advantage over the government in its ability to monitor participating firms and the sanctions it can levy on noncompliant parties. Moreover, we show that it is always possible that an independent enforcer of a voluntary agreement has a large enough advantage over the government that a voluntary agreement with member-financed enforcement can achieve an industry-wide emissions target more efficiently than an emissions tax. In these cases, the enforcement cost advantage of a voluntary agreement is greater than the loss from the inefficient distribution of emissions control responsibilities that Dawson and Segerson identify.

We also consider the possibility that government enforcement of a voluntary agreement is more efficient than member-financed enforcement. Voluntary agreements that are enforced by the government can be more efficient than those with member-financed enforcement, but only if the government's enforcement capabilities are significantly better than those of an alternative enforcer. However, we also show that there are no situations in which government-enforced voluntary agreements are more efficient than an emissions tax. Thus, our results suggest that voluntary emissions control agreements with industries can be an efficient means of achieving environmental quality goals, but only if: (1) the members of an agreement bear the costs of enforcing compliance with the agreement; (2) there exist member-financed agreements that reach the government's environmental quality target while leaving the members of the agreement at least as well off as they would be under an emissions tax, and (3) the enforcer of an agreement has a significantly better monitoring technology or a higher sanction available to it than the government.

2. Voluntary environmental agreements that do not require member-financed enforcement

Although Dawson and Segerson (2007) probably intended to assume away enforcement issues and their costs, one can interpret their results as arising from a model of a self-enforcing environmental agreement for which the government takes on the burden of enforcing compliance with the requirements of the agreement. In this section we present a somewhat simplified version of Dawson and Segerson's model of a self-enforcing environmental agreement to highlight the structure of these games, and to provide a baseline for our model of voluntary agreements with member-financed enforcement.

2.1 Basic setup

Following Dawson and Segerson (2007), we limit our analysis to an industry of n identical firms that emit a uniformly mixed pollutant. Each firm possesses a strictly concave profit function

$$\pi(e) = \beta + be - (b''/2)e^2, \qquad [1]$$

where β, b and b'' are positive constants and e denotes the emissions level of each firm.[3] We specify the form of the profit function to ease our computations in later sections of the paper. Absent an incentive to control its emissions, the firm chooses its emissions so that $\pi'(e) = 0$, yielding

$$e^u = b/b''. \qquad [2]$$

(The superscript u identifies uncontrolled emissions). The firm's profit when it is not motivated to control its emissions is

$$\pi(e^u) = \beta + \left(b^2/2b''\right). \qquad [3]$$

Suppose that the government seeks to reduce industry emissions by charging a per unit emissions tax t. Under the tax, each firm chooses its emissions to maximize

$$\pi(e) - te = \beta + be - (b''/2)e^2 - te, \qquad [4]$$

resulting in individual emissions

[3] A firm's profit function $\pi(e)$ describes its profit when its emissions are e and it makes all of its other input and output choices optimally.

$$e(t) = (b - t)/b'' . \quad [5]$$

For most of our analysis we consider taxes such that $0 < t < b$. Focusing on positive tax rates simply means that we are concerned with situations in which the government wishes to reduce the industry's emissions. Choosing tax rates below *b* means that we are mainly interested in situations in which the government does not seek a complete ban on the industry's emissions.[4]

Substituting [5] into [1] gives us each firm's gross profit under the tax:

$$\pi(t) = \pi(e(t)) = \beta + (b - t)(b + t)/2 . \quad [6]$$

Substituting $e(t) = (b - t)/b''$ into [3] yields each firm's profit net of their tax payment:

$$\pi(t) - e(t)t = \beta + (b - t)^2 / 2b'' . \quad [7]$$

Of course, a uniform emissions tax will lead to the distribution of emission control in the industry that maximizes industry profit, given that aggregate emissions are limited to $ne(t) = n(b - t)/b''$. The main contributions of Dawson and Segerson are that an aggregate emission target can always be achieved with a voluntary agreement, but that such an agreement will likely involve only a subset of firms who control their emissions while the remaining firms do not. Consequently, voluntary emissions control agreements with industries will not distribute individual emissions control efficiently. We now turn to the model of a self-enforcing agreement that produces this result.

2.2 A self-enforcing voluntary agreement

Suppose the government is willing to not impose the emissions tax if the industry can reach the desired level of emissions, $ne(t)$, through a voluntary emissions control agreement. Because

[4] We demonstrate later that a voluntary control agreement without member-financed enforcement that reduces industry emissions to zero can form, but it must include all firms in the industry. However, an agreement with member-financed enforcement cannot form to achieve a complete ban on the industry's emissions.

participation in the agreement is voluntary, individual firms freely choose whether they will become a member of the agreement. Participation with a voluntary agreement is modeled as a two-stage game. In the first stage, each firm decides independently whether to join the agreement. In the second stage, all firms choose their levels of emissions. Those who indicate that they will not join an agreement in the first stage choose their uncontrolled levels, e^u, in the second stage. In contrast, the members of the agreement commit to individual emissions standards that limit the entire industry's emissions to the government's aggregate target, provided that they can do so while remaining at least as well off as they would be under the emissions tax. If these conditions are met, then the government does not impose the tax and each member of the agreement holds their emissions to their agreed upon standard. These standards are chosen by the agreement members to maximize their joint profit, which, since the firms are identical, implies that they agree to uniform emission standards. If the firms that join a voluntary agreement in the first stage of the game cannot reduce their emissions far enough to meet the government's industry-wide target, or they are able to do so but they would be worse off than under the emission tax, they do not follow through with an agreement to reduce their emissions to meet the government's target. In response the government imposes the emissions tax.

The game is solved by backward induction. Let s denote the number of members of a voluntary agreement. To ease the exposition and later calculations, we assume that the number of firms is large enough so that s can be treated as a continuous variable.[5] Given s members of an agreement, let $e(s,t)$ denote the emissions standard that is required of each member of the agreement. Since nonmembers release their uncontrolled level of emissions e^u, aggregate

[5] All of the main results of this paper hold if we assume that s is a discrete variable. Making s discrete would make the analysis significantly messier without substantially improving our understanding of the issues.

emissions are $se(s,t)+(n-s)e^{u}$. In stage 2, therefore, an agreement with s members can meet the government's emissions target if and only if

$$se(s,t)+(n-s)e^{u} \leq ne(t)\,. \qquad [8]$$

Actually, the weak inequality in [8] can be replaced with strict equality, because there are no circumstances under which the members of a voluntary agreement will reduce their emissions so that industry emissions are lower than the government's target. The uniform emissions standard required of each member of a voluntary agreement to make sure that industry emissions are equal to the government's target is determined by letting [8] hold with equality, substituting $e(t)=(b-t)/b''$ and $e^{u}=b/b''$ from [2] and [5], and solving for $e(s,t)$:

$$e(s,t)=(sb-nt)/sb''. \qquad [9]$$

Note that $e(s,t)\geq 0$ if and only if $s\geq nt/b$. Therefore, voluntary agreements with participation levels in the interval $[nt/b,n]$ can meet the government's target, but agreements with less than nt/b members cannot, even if each of them reduced their emissions to zero.

Given $s\geq nt/b$, note that $e(s,t)$ is increasing in the number of members of an agreement, but is decreasing in the emissions tax. More members implies that the burden of holding industry emissions to $ne(t)$ is distributed among more firms. On the other hand, a higher emissions tax implies that the government is trying to induce a lower aggregate standard. Thus, given a fixed membership in a voluntary agreement, each member of the agreement must reduce its emission further to achieve the government's goal.

Now let us turn to the profit levels of the members and nonmembers of a voluntary agreement when its members are able to satisfy the government's aggregate emissions target. For $s\geq nt/b$, let $\pi_{m}^{nc}(s)$ denote the profit for each member of a voluntary agreement with s

members. (The subscript *m* indicates that the firm is a member of the agreement, while the superscript *nc* indicates that compliance with the agreement is enforced at *no cost* to its members). The following lemma specifies $\pi_m^{nc}(s)$ and states its characteristics. Its proof is in the appendix.

Lemma 1: For $s \in [nt/b, n]$, the profit for each firm in a voluntary emission control agreement that does not require member-financed enforcement is

$$\pi_m^{nc}(s) = \beta + \frac{(sb)^2 - (nt)^2}{2s^2 b''}, \qquad [10]$$

with the following characteristics:

(*i*) $\pi_m^{nc}(s = nt/b) < \pi(t) - e(t)t$;

(*ii*) $\partial \pi_m^{nc}(s) / \partial s > 0$;

(*iii*) $\pi_m^{nc}(s = n) - [\pi(t) - e(t)t] = t(b-t)/b'' > 0$;

(*iv*) $\pi_m^{nc}(s) < \pi(e^u)$.

The graph of $\pi_m^{nc}(s)$ is provided in Figure 1. At the lower bound of *s* for which an agreement can meet the government's target, $s = nt/b$, the profit for each member of an agreement is strictly less than their profit under the tax (*i*). However, $\pi_m^{nc}(s)$ increases with *s* (*ii*) and, under our assumption that $b > t$, $\pi_m^{nc}(s)$ exceeds $\pi(t) - e(t)t$ if all firms become members of the agreement (*iii*). In fact, if all firms join a voluntary agreement their individual emissions would be the same as under the tax, so that the difference between $\pi_m^{nc}(s = n)$ and $\pi(t) - e(t)t$ is simply their individual tax payments. Of course, avoiding these taxes is the motivation to form a voluntary agreement in the first place. Note, however, that the profit of any firm that refuses to join a voluntary agreement, $\pi(e^u)$, will always be higher than the profit of a member of the agreement (*iv*), simply because nonmembers do not control their emissions. Therefore, while it is clear that the incentive and opportunity exist to form a cooperative agreement to avoid the emissions tax, it is also quite clear that every firm is motivated to free-ride on efforts to do so.

Note in Figure 1 that there exist coalitions that are profitable in the sense that each member of these coalitions is at least as well off as under the emissions tax. Use [10] and [7] to solve $\pi_m^{nc}(s) = \pi(t) - e(t)t$ for s to obtain the smallest of these coalitions:

$$s_{\min}^{nc} = n\sqrt{t/(2b-t)}. \qquad [11]$$

Since voluntary emissions control agreements form only when their members find them profitable, if $s \geq s_{\min}^{nc}$ firms join an agreement in the first stage of the game, each of them reduces their emissions to $e(s,t)$, defined by [9]. However, if $s < s_{\min}^{nc}$ firms join in the first stage, they would be better off by simply accepting the emissions tax. In this case, they will not follow through with emissions standards to satisfy the government's aggregate goal, and the government responds by imposing the emissions tax on all firms.

To determine the number of firms that will join a voluntary emissions control agreement in the first stage, Dawson and Segerson (2006) adopt the equilibrium concept of a *self-enforcing* agreement that is employed in the study of cartels (D'Aspremont et al. 1983), and international environmental agreements (Barrett 1994; Kolstad 2007). Let s^{nc} denote the equilibrium number of members of a voluntary environmental agreement that does not require member-financed enforcement. The definition of a *self-enforcing voluntary agreement* in this setting is:

Definition: A voluntary emissions control agreement consisting of s^{nc} firms that do not bear the costs of enforcing the agreement is self-enforcing if and only if:

(*i*) $\pi_m^{nc}(s^{nc}) \geq \pi(e^u)$ if $s > s_{\min}^{nc}$, and $\pi_m^{nc}(s^{nc}) \geq \pi(t) - e(t)t$ if $s = s_{\min}^{nc}$;

$(ii)\ \ \pi(e^u) \geq \pi_m^{nc}(s^{nc}+1)\ .$ [12]

Requirement (i) of a self-enforcing voluntary agreement is the *internal stability* condition that no member of the agreement has an incentive to leave the agreement, while requirement (ii) is the *external stability* condition that no nonmember wishes to join the agreement. Dawson and Segerson (2006) prove that a self-enforcing voluntary emission control agreement always exists, and that the only internally and externally stable voluntary agreement is the one with $s^{nc} = s_{\min}^{nc}$ members. These conclusions also hold for our version of their model.

Proposition 1: A *self-enforcing* voluntary emissions control agreement that does not require member-financed enforcement always exists. The equilibrium number of members of such an agreement is

$$s^{nc} = s_{\min}^{nc} = n\sqrt{t/(2b-t)}. \quad [13]$$

It is easy to show why this proposition holds, so we do not offer a formal proof. A self-enforcing agreement always exists as long as profitable agreements exist. Figure 1 clearly illustrates that all coalitions involving memberships greater than or equal to $s_{\min}^{nc}$ are profitable. To see why the only self-enforcing number of members of a voluntary agreement is $s_{\min}^{nc}$, note first that if $s^{nc} > s_{\min}^{nc}$, then at least one member of s^{nc} could leave the agreement to earn the free-riding payoff, $\pi(e^u) > \pi_m^{nc}(s)$, without having the agreement collapse. Thus, no coalitions with more than $s_{\min}^{nc}$ members are internally stable. However, a coalition with exactly $s_{\min}^{nc}$ members is internally stable, because one fewer member would leave the remaining members worse off than under the emissions tax. They would then refuse to control their emissions and the tax would be imposed on all firms. Finally, an agreement with $s^{nc} = s^{nc}_{\min}$ members is externally stable. No nonmember would join this agreement, because they earn more by free riding.

In the self-enforcing equilibrium, members of the agreement earn just what they would under the emissions tax while nonmembers earn the free-riding payoff. Thus, industry profits are strictly greater under voluntary emission control than under the emissions tax. However, Dawson and Segerson show that a voluntary agreement cannot be efficient. In the absence of enforcement costs, the efficient allocation of pollution control maximizes the industry's aggregate gross profit given that aggregate emissions are equal to the government's target. With identical firms this requires that all firms reduce their emission to the same level. Under a voluntary agreement, however, only the members of the agreement reduce their emissions. Thus, Dawson and Segerson conclude that if the government wishes to achieve an environmental quality objective efficiently, it would never prefer voluntary control of emissions to an emissions tax.[6]

It is clear, however, that the concept of a self-enforcing agreement is concerned with the stability of a cooperating coalition, not with the members' decisions to comply with their commitments once they've joined. If firms' emissions are not easily observed and the government's decision to allow a voluntary agreement is not easily reversed, then a firm may be motivated to join an agreement to help forestall the emissions tax, but decide not to reduce its emissions to the extent required under the agreement. Thus, a more realistic model of a voluntary

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[6] To illustrate this result, subtract aggregate profit under the voluntary agreement, $\pi_p^{nc}(s^{nc})s^{nc} + \pi(e^u)(n - s^{nc})$, from aggregate gross profit under the emissions tax, $n\pi(t)$ to obtain

$$n\pi(t) - \left[\pi_m^{nc}(s^{nc})s^{nc} + \pi(e^u)(n - s^{nc})\right] = \left(nt^{3/2}/2b''\right)\left(\sqrt{2b-t} - t^{1/2}\right) > 0.$$

The sign follows from the fact that $b > t$ makes $\sqrt{2b-t} > t^{1/2}$. Note, however, that setting $b = t$ to achieve of complete ban on emissions makes a voluntary agreement and the emissions tax equally efficient. This is because the self-enforcing agreement to achieve a ban on industry emissions requires the participation of all firms in the industry. To see this, note from [13] that $s^{nc} = s^{nc}_{\min} = n$ when $b = t$.

emissions control agreement should include an enforcement dimension. Moreover, the relative costs of enforcing a voluntary agreement and enforcing an emissions tax, as well as who bears the costs of enforcing the agreement, will impact the relative efficiency of these agreements. In the next section we extend Dawson and Segerson's (2007) model to include member-financing of an independent enforcer who is responsible for maintaining compliance with the terms of a voluntary emissions control agreement.

3. Voluntary environmental agreements with member-financed enforcement

We now give the members of a voluntary emissions control agreement the opportunity to violate the emissions standard specified under the agreement. To counteract the incentive toward noncompliance the members of an agreement fund an independent enforcer who monitors the firms' emissions and applies a penalty when it finds a violation.

As before the model is analyzed as a stage game, but now the game has four stages. The first stage (*membership stage*) is the same as before, that is, each firm chooses independently whether to join a voluntary agreement. In stage two (*agreement stage*), member firms jointly agree on whether to reduce their emissions to meet the government's emissions target. If they agree to meet the target, each of them contributes sufficient funds to the enforcer to maintain their compliance with the agreement's emissions standard. If this occurs, the government does not impose the emissions tax. If the agreement members jointly decide not to meet the government's target in stage two (or cannot because of lack of participation), they do not fund the enforcer, an effective agreement does not form, the government imposes the emissions tax, and the game ends. (Throughout, we refer to an *effective* voluntary agreement as one that actually leads to voluntary achievement of the aggregate emissions target in place of an emissions tax). If an agreement forms in stage two, both members and nonmembers of the agreement independently choose their emissions in stage three (*emissions stage*). Finally, in the fourth stage (*enforcement stage*) the enforcer of the agreement randomly audits the emissions of member firms with the funding provided to it in the second stage, and applies a sanction when a violation is discovered. Since the agreement, emissions, and enforcement stages are new with this study, we need to describe them in more detail. Because the game is solved by backward induction, we start with the last stage.

3.1 Enforcement stage

If the game reaches this stage a voluntary agreement with s members has formed, they have agreed to reduce their emissions to meet the government's target, each of them has made a contribution to fund the enforcer, and all firms have chosen their emissions. In the enforcement stage, the monitor randomly audits the emissions of the agreement members and applies a sanction in cases of noncompliance.

The monitoring technology of the independent enforcer is specified in a straightforward manner. Monitoring consists of $a \le s$ random audits of the members. An audit of a firm reveals its compliance status without error. If each member of the agreement contributes x to the enforcer, it can audit $a = \alpha s x$ members, where α is interpreted as the constant marginal productivity of enforcement resources in producing audits. Since audits are random, the probability that any one firm will be audited is

$$\rho = a / s = \alpha x. \qquad [14]$$

Note that given a fixed contribution by each member of the agreement, increasing the number of members does not change the audit probability because each additional member contributes enough to keep that probability constant. However, we will see shortly that the contribution of each member, and hence the audit probability, will depend on the number of members. Moreover, we will demonstrate exactly what is required to make $\rho \in (0,1]$.

A member of a voluntary agreement is noncompliant when its emissions exceed the emissions standard that is necessary for the member firms to meet the government's aggregate target. Recall that this standard is $e(s,t)$ from equation [9]. If the enforcer finds a firm in violation it imposes a unit fine of f on $e - e(s,t) > 0$. Note that each firms faces the expected marginal penalty $\rho f = \alpha x f$. The fine is constrained to be no more than $\overline{f}$.

3.2 Emissions stage

At this point in the game the members of a voluntary agreement have agreed to reduce their emissions to meet the government's target and have funded the enforcer. In the emissions stage both members of the agreement and nonmembers independently choose their emissions. Nonmembers have no incentive to control their emissions, so they each choose their uncontrolled levels e^u specified by [2]. Member firms, however, hold their emissions to $e(s, t)$ if and only if the agreement is enforced adequately. To simplify the analysis, we restrict ourselves to enforcement strategies that guarantee full compliance by the members of the agreement.[7]

Assume that the firms are risk neutral and that members of an agreement comply with its emissions standard if they are at least indifferent between compliance and noncompliance. Each of them chooses their emissions to maximize their expected net profit; that is, they solve

$$\max_e \pi(e) - \rho f(e - e(s,t)), \quad s.t.\ e \geq e(s,t). \qquad [15]$$

[7] One can envision a voluntary agreement that reaches the government's aggregate emissions target despite allowing a certain amount of noncompliance by its members. It is not clear, however, that there is any gain in doing so over an agreement with sufficient enforcement to induce full compliance.

The Kuhn-Tucker conditions for a solution to [15] are $\pi'(e)-\rho f \le 0$, $e-e(s,t) \ge 0$, and $[\pi'(e)-\rho f][e-e(s,t)]=0$. These conditions indicate that all parties will comply with the standard as long as $\rho f \ge \pi'(e(s,t))$; that is, as long as the expected marginal penalty for violating the standard is not less than a firm's marginal profit evaluated at the standard. This guarantees that a firm's marginal benefit from noncompliance— $\pi'(e)$ for $e \ge e(s,t)$ — is never greater than the expected marginal penalty.

Since monitoring is costly, the members of the agreement will provide sufficient funds to the enforcer in stage two of the game so that it can induce full compliance with minimal monitoring. This requires $\rho f = \pi'(e(s,t))$, yielding the audit probability $\rho = \pi'(e(s,t))/f$. Use [1] and [9] to calculate $\pi'(e(s,t))$ and substitute the result into $\rho = \pi'(e(s,t))/f$ to obtain

$$\rho = nt/sf. \qquad [16]$$

Clearly, $nt \le sf$ is a necessary condition for an effective voluntary agreement. If this condition did not hold, then the enforcer would not be able to maintain compliance with the agreement, even if it audited each of its members. Note that the combination of low sanctions and lack of participation can prevent the formation of a voluntary agreement. For the remainder of this analysis we assume that $nt \le sf$ to allow an effective agreement to form.

Not surprisingly, ρ is decreasing in the fine. More interestingly, it is also decreasing in the number of members of the agreement. Recall that $e(s,t)=(sb-nt)/sb''$ is increasing in s, reflecting the fact that the individual burden of meeting the government's target is reduced if an agreement contains more members. That $\pi'(e(s,t))$ is then decreasing in s tells us that an individual member's incentive to violate the agreement's standard is reduced as the number of members is increased. Consequently, the minimum audit probability that is necessary to maintain full compliance can be reduced. On the other hand, an increase in the threatened tax implies that the government's aggregate emissions target is lower. Members of an agreement must then reduce their emissions further. Since they each have a greater incentive to violate a lower standard, the audit probability required to maintain their compliance must increase as the emissions tax is increased.

3.3 Agreement stage

The firms that agree to join a voluntary emissions control agreement in the first stage agree to reduce their emissions to meet the government's target and fund the enforcer in the agreement stage as long as these decisions maximize their joint welfare. It is important to note that firms cannot credibly commit to reducing their emissions in this stage because their emissions are only revealed later if they are audited. In the agreement stage member firms only state that they will reduce their emissions in the emissions (third) stage. On the other hand, the individual payments to the enforcer are easily observed. To preclude the possibility that a firm can agree to make this payment and then fail to do so, we require that the payment be made in this stage if an effective agreement forms.

To determine the payment each member of an effective voluntary agreement makes to the enforcer, combine [16] and [14] and solve for x to obtain $x = nt / s\alpha f$. Since x is monotonically decreasing in the fine for noncompliance, the members of the agreement will all agree that the fine should be as high as possible; that is, $f = \overline{f}$.[8] Thus, the contribution to the enforcer of an effective agreement with s members is

[8] The idea that the penalty for noncompliance should be set as high as possible to conserve monitoring costs when agents are risk neutral is common in the literature on the economics of law enforcement. See Polinsky and Shavell (2000) for a review of this literature.

$$x(s) = nt / s\alpha \overline{f}. \qquad [17]$$

The required payment is decreasing in the number of members of the agreement and increasing in the tax, simply because the minimum audit probability that is required to maintain compliance with an effective agreement (given by equation [16]) is also decreasing in the number of members and increasing in the tax.

Members of a voluntary agreement will agree to a uniform emissions standard to meet the government's target and to fund the enforcer if and only if they are at least as well off as under the emission tax; that is, the agreement must be profitable for each of its members. We explore the profitability of voluntary agreements with member-financed enforcement thoroughly in the next section. For now, let us just say that profitability depends on the number of firms that decide to join the agreement in the first stage of the game (i.e., the membership stage). If a sufficient number of firms join the agreement in the first stage, they will agree to an emissions standard to meet the government's target and fund the enforcer in the second. In response, the government does not impose the emissions tax. Since funds for the enforcer are sufficient to guarantee full compliance, in the third stage each member complies with the agreed-upon standard. In the fourth stage the enforcer conducts its random audits of the members' emissions, but finds no violations. On the other hand, if too few firms join the agreement in the first stage, the agreement will not be profitable. The members then do not agree to control their emissions, there is no need to fund the enforcer, and the government imposes the tax on all firms.

4. Equilibrium voluntary agreements that require member-financed enforcement

The subgame perfect equilibrium of the stage game we've just described is either a self-enforcing agreement under which all members of the agreement limit their emissions to meet the government's aggregate target, or an effective agreement does not form and the government imposes the emissions tax. In this section we derive the equilibrium number of members of a self-enforcing voluntary agreement with member-financed enforcement and compare it to the equilibrium obtained under the assumption that an agreement does not require member-financed enforcement. We begin by examining the profitability requirement of voluntary emissions control agreements with member-financed enforcement.

4.1 Profitable voluntary agreements

Recall from subsection 2.1 that to reach the government's aggregate emissions target, each member of a voluntary agreement must hold their emissions to $e(s, t)$ defined by [9], which they are able to do if and only if $s \geq nt/b$. Otherwise, an effective agreement cannot form. Moreover, recall from [16] and the discussion that followed that to guarantee that the enforcer of an agreement can maintain compliance with its emissions standard we also need $nt \leq s\overline{f}$, or $s \geq nt/\overline{f}$,. To focus on situations in which an effective agreement with member-financed enforcement can actually form, we limit our analysis to agreements with memberships $s \in \left[\max(nt/b, nt/\overline{f}), n\right]$.

The profit of each member of a voluntary agreement consists of its gross profit from holding its emissions to $e(s, t)$ minus its payment to the enforcer $x(s)$ defined by [17]. For $s \in \left[\max(nt/b, nt/\overline{f}), n\right]$, let $\pi_m^c(s)$ denote the profit for each member of a voluntary agreement that requires member-financed enforcement. (The superscript c indicates that compliance with an agreement requires member-financed enforcement). The following lemma specifies $\pi_m^c(s)$ and states some of its characteristics. It is proved in the appendix.

Lemma 2: For $s \in \left[\max(nt/b, nt/\overline{f}), n\right]$, the profit for each firm in a voluntary emissions control agreement that requires member-financed enforcement is

$$\pi_m^c(s) = \pi_m^{nc}(s) - x(s) = \beta + \frac{(sb)^2 - (nt)^2}{2s^2 b''} - \frac{nt}{s\alpha \overline{f}}, \qquad [18]$$

with the following characteristics:

i) $\pi_m^c(s) < \pi_m^{nc}(s)$;

ii) $\partial \pi_m^c(s) / \partial s > 0$;

iii) there exist s such that $\pi_m^c(s) \geq \pi(t) - e(t)t$ if and only if $(b-t) \geq b''/\alpha\overline{f}$.

Not surprisingly, [18] indicates that, for a given *s*, the difference between the profit of the members of an agreement that does not require member-financed enforcement and the profit of the members of an agreement with member-financed enforcement is simply the payment the members of the latter form of agreement pay to fund its enforcer. This implies that the profit of each member of an agreement with member-financed enforcement is less for every level of *s* (part *i*). Equally unsurprising is the fact that the profit of each member of an agreement is increasing in the number of members (part *ii*). Part *iii*) is much more interesting, because it reveals whether profitable agreements with member-financed enforcement actually exist.[9] Recall from section 2 that profitable agreements that do not require member-financed enforcement always exist. However, there is nothing in the model with member-financed enforcement that requires or implies $(b-t) \geq b''/\alpha\overline{f}$. Since only a profitable agreement can form in place of an emissions tax, we have our first conclusion about the impact of member-financed enforcement on self-enforcing voluntary emissions control agreements.

[9] In the very special case that $(b-t) = b''/\alpha\overline{f}$, the only profitable agreement is the one that contains all of the firms in the industry (i.e., $s = n$).

Proposition 2: The circumstances under which an effective voluntary emission control agreement can form are diminished by enforcement costs that are borne by the members of an agreement.

That $(b-t) \geq b''/\alpha\bar{f}$ is required for an effective agreement reveals that the costs of enforcement can be sufficiently high to prevent an agreement from forming. Loosely, the likelihood that an agreement can form is reduced as the marginal productivity of monitoring resources, α, or the size of the maximum available sanction, $\bar{f}$, is reduced. Reducing either of these parameters increases the payment to the enforcer required of all agreement members, which leads to a decrease in the set of opportunities for an effective agreement.

4.2 A self-enforcing voluntary agreement that requires member-financed enforcement

Like the model of self-enforcing voluntary agreements without member-financed enforcement in section 2, a self-enforcing agreement with member-financed enforcement must be both internally and externally stable. Again like the model of section 2, it is easy to show that the only internally and externally stable coalition size is the smallest profitable coalition, provided that a profitable coalition actually exists From Lemma 2 and the discussion that followed, profitable agreements with member-financed enforcement exist if and only if $(b-t) \geq b''/\alpha\bar{f}$. Under this condition, the smallest profitable coalition is:

$$s_{\min}^{c} = s \mid \left[\pi_m^c(s) = \pi(t) - e(t)t\right] = \frac{nb'' + n\sqrt{b''^2 + (\alpha\bar{f})^2(2b-t)t}}{\alpha\bar{f}(2b-t)}. \qquad [19]$$

Therefore, we have:

Proposition 3: Let s^c be the equilibrium number of members of a self-enforcing voluntary emission control agreement that requires member-financed enforcement. Then, $s^c = s^c_{\min}$ provided that $(b-t) \geq b''/\alpha\bar{f}$. If $(b-t) < b''/\alpha\bar{f}$, then a voluntary agreement will not form and the government will impose the emissions tax.

Comparing [19] to [13] reveals clearly that member-financed enforcement of effective voluntary agreements changes the self-enforcing number of members of these agreements. To see how, subtract [13] from [19] to obtain:

$$s^c - s^{nc} = \frac{b''n + n\sqrt{b''^2 + (\alpha\bar{f})^2 t(2b-t)} - n\alpha\bar{f}\sqrt{t(2b-t)}}{\alpha\bar{f}(2b-t)}. \qquad [20]$$

To sign this expression note that it is increasing in b'' and is equal to zero when $b''=0$. Since we assume $b''>0$, $s^c - s^{nc} > 0$. This proves our next proposition.

Proposition 4: If an effective voluntary emission control agreement with member-financed enforcement forms, the number of members of the agreement will be greater than under a voluntary agreement that does not require member-financed enforcement.

The reason for this result is straightforward. Since contributing to the enforcement of a voluntary agreement is an additional cost of joining one, more firms are required to participate to make the agreement profitable.

Figure 2 illustrates the main differences between effective agreements that require member-financed enforcement and those that do not. We have graphed $\pi_m^{nc}(s)$ along with a candidate for $\pi_m^c(s)$ that allows an agreement with member-financed enforcement to form.[10] From Lemma 2, $\pi_m^c(s)$ is monotonically increasing in *s* and the vertical difference between

[10] Note that we assume that $\max(nt/b, nt/\bar{f}) = nt/b$ so that $s \in [nt/b, n]$.

$\pi_m^{nc}(s)$ and $\pi_m^c(s)$ is simply the payment each member of a costly-to-enforce agreement pays to its enforcer. Moreover, we assume that $(b-t) \geq b''/\alpha \bar{f}$ so that profitable agreements exist.[11] From Proposition 3, the smallest of these profitable coalitions, s^c, is the equilibrium number of members of an effective agreement that requires member-financed enforcement. That $s^c > s^{nc}$ in Figure 2 clearly illustrates Proposition 4.

When a voluntary agreement that requires member-financed enforcement forms the number of free-riders on the agreement will be less than if the agreement did not require costly enforcement, or if the government enforced the agreement. Recall that Dawson and Segerson (2007) showed that free-riding makes voluntary agreements inefficient in the sense that aggregate industry profit at the government's aggregate emissions target is not maximized. Since free-riding is reduced when agreement members finance their own enforcement, the inefficiency associated with free-riding is also less. But whether an effective voluntary agreement with member-financed enforcement can ever be more efficient than an emissions tax requires that we include the relative costs of enforcing voluntary agreements and emissions taxes in a welfare comparison of the two policy approaches. The relative efficiency of voluntary emissions control agreements and emissions taxes is the topic of the next section.

5. The relative efficiency of voluntary environmental agreements

5.1 The cost of enforcing an emissions tax

To compare the relative efficiency of a voluntary agreement and an emissions tax, we first need to derive the cost of enforcing a tax. Under an emissions tax, each firm in the industry is

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[11] If $(b-t) < b''/\alpha \bar{f}$, then $\pi_m^c(s)$ would lie below $\pi(t) - e(t)t$ for each s, and no profitable agreement would exists. In the special case that $(b-t) = b''/\alpha \bar{f}$, $\pi_m^c(s)$ would lie below $\pi(t) - e(t)t$, except at $s = n$.

required to submit a report of its emissions, r, and it is noncompliant if it attempts to evade some part of its tax liability by reporting $r < e$. After the firms release their emissions and submit their emission reports, the government randomly audits the emissions of some subset of the firms so that the probability that any one of them is audited is ρ^g. (The superscript g identifies parameters and variables associated with the government's enforcement capabilities. In general, these will be different from those of an independent enforcer of a voluntary agreement). If a firm is audited and their reported emissions are lower than their actual emissions, the firm is fined $f^g \le \overline{f}^g$ per unit of $e - r > 0$. As with the enforcement of a voluntary agreement, we assume that government enforces the emissions tax so that all firms are compliant.[12]

Assuming for simplicity that firms always choose positive emissions, a risk neutral firm chooses its actual and reported emissions to maximize

$$\pi(e) - tr - \rho^g f^g (e - r), \text{ s.t. } e \ge r \ge 0 . \qquad [21]$$

The constraint $e - r \ge 0$ is imposed because a firm will never have an incentive to over-report its emissions. Let $\mathcal{L}$ denote the Lagrange equation for [21] and let λ denote the multiplier attached to the constraint $e - r \ge 0$. Then, the following first-order conditions are both necessary and sufficient to determine the firm's choices of emissions and emissions report:

$$\mathcal{L}_e = \pi'(e) - \rho^g f^g + \lambda = 0; \qquad [22]$$

$$\mathcal{L}_r = -t + \rho^g f^g - \lambda \le 0,\ r \ge 0,\ r(t - \rho^g f^g - \lambda) = 0; \qquad [23]$$

$$\mathcal{L}_\lambda = e - r \ge 0,\ \lambda \ge 0,\ \lambda(e - r) = 0. \qquad [24]$$

[12] Contributions to the theoretical literature on compliance and enforcement of emissions taxes include Harford (1978 and 1987), Sandmo (2002), Cremer and Gahvari (2002), and Macho-Stadler and Perez-Castrillo (2006). Recently, Stranlund et al (2007) argue that it is normally efficient to enforce emissions taxes so that firms are compliant if the costs of sanctioning noncompliant firms are greater than the costs of collecting tax revenue.

Under the assumption that a firm will comply if it is indifferent between compliance and noncompliance, [23] and [24] reveal that inducing truthful reporting requires that the tax not exceed the expected marginal penalty for under-reported emissions; that is, $t \le \rho^g f^g$. If the inequality was reversed, the firm would report zero emissions because it would be cheaper to face the expected penalty than to pay the tax. Moreover, to minimize the monitoring costs of inducing full compliance, the government sets the fine at its maximum level, $f^g = \overline{f}^g$, and monitors so that $t = \rho^g \overline{f}^g$. Finally, since $r = e > 0$, [23] becomes $\mathcal{L}_r = 0$. Then, combining [22] and [23] yields $\pi'(e) = t$. Using a firm's profit function, $\pi(e)$ defined by [1], each firm's gross profit under the tax is defined by [5] and its profit net of its tax payment is defined by [7].

In enforcing the emission tax the government has the same sort of linear monitoring technology as the independent enforcer of an alternative voluntary agreement. Let $x(t)$ denote the per-firm amount of money the government spends on auditing firms under the tax. If the marginal productivity of monitoring resources is the constant α^g, then the audit probability each firm faces is $\rho^g = \alpha^g nx(t)/n = \alpha^g x(t)$. Moreover, since the government audits just enough firms so that $t = \rho^g \overline{f}^g$, the per-firm cost of enforcing the emissions tax is $x(t) = t/\alpha^g \overline{f}^g$, and aggregate enforcement costs are

$$nx(t) = nt/\alpha^g \overline{f}^g \ . \qquad [25]$$

5.2 Can a voluntary emissions control agreement be more efficient than an emissions tax?

Before we turn to a full specification of the efficiency of a voluntary agreement relative to an emission tax, we first explore the issue of whether a voluntary agreement can be enforced more cheaply than a tax as suggested by Bailey (1999), Schmelzer (1999), and Nyborg (2000). Use

[25] and [17] to calculate the difference between the cost of enforcing a voluntary agreement and the cost of enforcing an emissions tax:

$$nx(t) - s^c x(s^c) = \frac{nt}{\alpha \bar{f}} - \frac{nt}{\alpha^g \bar{f}^g}. \qquad [26]$$

Clearly, if the enforcer of a voluntary agreement and the government have identical monitoring technologies and available sanctions, then there is no difference in the costs of enforcing a voluntary agreement and an emissions tax that induce the same aggregate emissions. There are two equal but opposing forces at work here. Given an audit probability, the number of firms that need to be audited under a voluntary agreement is less than under an emissions tax, because only a subset of the firms operate under the agreement. On the other hand, monitoring costs are higher under a voluntary agreement because each member firm is required to reduce its emissions to a lower level than under the emissions tax; hence, they need to be monitored more closely to offset the greater incentive to be noncompliant.

Except in the special case that $s^c = n$, if the enforcer of the agreement and the government have the same enforcement capabilities, a voluntary agreement with member-financed enforcement will not be a more efficient policy than an emissions tax simply because these agreements fail to allocate individual emissions control efficiently.[13] Therefore, if it is possible that a voluntary approach can outperform an emissions tax when $s^c < n$, the enforcer of the agreement has to be significantly better at monitoring firms' emissions than the government (i.e., $\alpha > \alpha^g$), or it must be able to impose significantly higher penalties ($\bar{f} > \bar{f}^g$), or some combination of the two that makes $\alpha \bar{f} > \alpha^g \bar{f}^g$. We now explore this possibility.

[13] In the case that $s^c = n$, if the costs of enforcing the voluntary agreement and the emissions tax are the same, then the voluntary approach and the tax are equally efficient, because there is no free-riding loss under the voluntary approach.

Our welfare measure is aggregate industry profit less the aggregate cost of enforcement. This value is $V^t = n\pi(t) - nx(t)$ under the emissions tax. Note that we are assuming that tax revenue is a simple transfer with no real effects. Aggregate welfare under the voluntary agreement with member-financed enforcement is $V^c = \pi_m^c(s^c)s^c + \pi(e^u)(n - s^c)$. Recall from [18] that $\pi_m^c(s^c)$ includes the payment a member of a voluntary agreement must make to the enforcer of the agreement; hence, V^c includes the total cost of enforcing an agreement. The difference between welfare under the emissions tax and the voluntary agreement is

$$V^t - V^c = n\pi(t) - nx(t) - \left[\pi_m^c(s^c)s^c + \pi(e^u)(n - s^c)\right]. \qquad [27]$$

Upon substitution of $\pi(t)$ from [6], $nx(t)$ from [25], s^c from [19], $\pi_m^c(s)$ from [18], and $\pi(e^u)$ from [2], we have:

$$V^t - V^c = \frac{nt(n - s^c)}{2b''s^c} + \frac{nt}{\alpha \overline{f}} - \frac{nt}{\alpha^g \overline{f}^g}. \qquad [28]$$

Note that the second and third terms of [28] capture the difference between the cost of enforcing the voluntary agreement and the cost of enforcing the emissions tax (see [26]). The first term, which is non-negative because $n \geq s^c$, is the gain in aggregate gross profit of the industry under the emissions tax over the voluntary agreement, because there is no free-riding loss under the emission tax. Equation [28] reveals clearly that $V^t > V^c$ if $\alpha \overline{f} = \alpha^g \overline{f}^g$ and $n > s^c$.[14] Just as clearly, if the government has the enforcement advantage so that $\alpha \overline{f} < \alpha^g \overline{f}^g$, then a voluntary agreement with member-financed enforcement will never be more efficient than an emissions tax. However, our next proposition reveals that it is *always possible*

[14] This is simply a formal demonstration of our earlier statement that if the enforcer of a voluntary agreement and the government have the same monitoring technology and sanction, an emissions tax is a more efficient way to achieve an aggregate emissions target than a voluntary agreement that involves only a subset of the firms.

that the enforcer of the voluntary agreement has enough of an advantage over the government to make a voluntary agreement more efficient than an emissions tax. In these cases, the saving in enforcement costs over the costs of enforcing an emissions tax is greater than the free-riding loss that plagues voluntary agreements. Proposition 5 is proved in the appendix.

Proposition 5: An effective voluntary agreement with member-financed enforcement is more efficient than an emissions tax if and only if $\alpha^g \bar{f}^g < \left(\alpha^g \bar{f}^g\right)^0$, where $\left(\alpha^g \bar{f}^g\right)^0$ is the unique solution to $V^t = V^c$ and is strictly positive and strictly less than $\alpha \bar{f}$.

Our conclusion that it is always possible that a voluntary agreement is more efficient than an emissions tax comes from the fact that the cut-off value, $\left(\alpha^g \bar{f}^g\right)^0$, in Proposition 5 is strictly greater than zero. In the proof of the proposition we show that $V^t - V^c$ is monotonically increasing in $\alpha^g \bar{f}^g$ and $V^t > V^c$ when $\alpha \bar{f} = \alpha^g \bar{f}^g$. Therefore, there is a value of $\alpha^g \bar{f}^g$ at which $V^t = V^c$, which is $\left(\alpha^g \bar{f}^g\right)^0$. If this value was negative, then we would have $V^t > V^c$ for all positive values of $\alpha^g \bar{f}^g$, and a voluntary agreement could never outperform an emissions tax. That it is positive implies that there is a range of positive values of $\alpha^g \bar{f}^g$ for which a voluntary agreement is more efficient than an emissions tax. That values in this range are strictly less than $\alpha \bar{f}$ indicates that a voluntary agreement can only be more efficient than an emission tax when the enforcer of the agreement has a significant advantage over the government in its monitoring capability and/or available sanction.

5.3 Should the government enforce voluntary emissions control agreements?

We have one final issue to deal with. Throughout most of the paper we have assumed that the members of a voluntary agreement finance the enforcement of the emissions standard they agree to. One could envision, however, a situation in which the government allows a voluntary agreement in place of an emission tax and takes on the burden of enforcing the agreement. In this subsection we examine the efficiency of government enforcement of a voluntary agreement.

In our review of Dawson and Segerson's (2007) model in section 2, we noted that one could interpret their model as one in which the government enforcers the requirements of an agreement. Thus, when the government enforces a voluntary agreement the equilibrium number of members of the agreement is s^{nc} defined in Proposition 1, and the per-firm profit of the members of the agreement is $\pi_m^{nc}(s^{nc})$, where $\pi_m^{nc}(s)$ is specified in Lemma 1. Hence, aggregate profit when the government enforces a voluntary agreement is $\pi_m^{nc}(s^{nc})s^{nc} + \pi(e^u)(n - s^{nc})$. The government maintains the compliance of the members of the agreement with its monitoring parameter and maximum fine, α^g and $\overline{f}^g$. Using [17], the government's total cost of enforcing the agreement is $x(s^{nc})s^{nc} = nt\big/\alpha^g \overline{f}^g$. Let us denote the value of a voluntary agreement that is enforced by the government as $V^{c/g}$. Then,

$$V^{c/g} = \pi_m^{nc}(s^{nc})s^{nc} + \pi(e^u)(n - s^{nc}) - nt\big/\alpha^g \overline{f}^g . \qquad [29]$$

Recall that aggregate welfare under a voluntary agreement with member-financed enforcement is $V^c = \pi_m^c(s^c)s^c + \pi(e^u)(n - s^c)$.

Our last proposition reveals that while it may be more efficient for the government to enforce a voluntary agreement, it is always more efficient for it to impose the emissions tax instead. The proof is in the appendix.

Proposition 6: Government enforcement of a voluntary environmental agreement is more efficient than member-financed enforcement if and only if $\alpha^g \overline{f}^g$ exceeds $\left(\alpha^g \overline{f}^g\right)^1 > \alpha \overline{f}$, where $\left(\alpha^g \overline{f}^g\right)^1$ is the unique solution to $V^c - V^{c/g} = 0$. However, it is always more efficient for the government to impose the emissions tax than to allow a voluntary agreement that it enforces.

Proposition 6 suggests that it is possible that government enforcement of a voluntary agreement is more efficient than member-financed enforcement, but only if the government is significantly better at enforcement. The reason for this result is that participation with a voluntary agreement is less when the government takes on the enforcement costs than when these costs are borne by the members of an agreement. Thus, free-riding and its associated loss are greater when the government bears the enforcement costs. The government's enforcement advantage must then be large enough to overcome this extra loss if it is to be more efficient for it to enforce a voluntary agreement than to insist that the members of the agreement bear the enforcement costs. However, a voluntary agreement that the government enforces is never more efficient than an emissions tax. Hence, if the government is motivated by the efficient achievement of an environmental quality goal, it should never allow a voluntary agreement among polluting firms that it intends to enforce.

6. Conclusion

Voluntary agreements made between the government and industries are increasingly being considered as viable alternatives to more traditional forms of environmental regulation. These approaches are often credited with a number of cost-saving advantages over traditional regulations, including the possibility that they are cheaper to enforce. To our knowledge we are the first to model compliance with the requirements of voluntary agreements and the costs of enforcing these requirements rigorously. Clearly, any analysis of the relative efficiency of voluntary versus regulatory approaches must address the relative costs of enforcing the two approaches, and who bears the costs of enforcing voluntary agreements.

Our efforts have provided several new results that have significant relevance for our understanding of the efficacy and efficiency of voluntary emissions control agreements. When firms that participate in a voluntary control agreement finance an independent enforcer to maintain compliance with the agreement, the circumstances under which a voluntary agreement can form in place of an emissions tax are diminished. However, when such an agreement does form, more firms will participate in the agreement than if the agreement could be enforced without cost, or if the government took on the costs of enforcing the agreement. In general, an environmental agreement with member-financed enforcement is not cheaper to enforce than an emissions tax that achieves the same level of environmental quality. However, it is always possible that an independent enforcer of a voluntary agreement has enough of an advantage over the government that a voluntary agreement with member-financed enforcement is a more efficient means of achieving an environmental quality target than an emissions tax. Finally, we have shown that there are no circumstances under which the government should take on the costs of enforcing a voluntary agreement, because government-enforced agreements are always less efficient than an emissions tax.

In short, our results suggest that voluntary emissions control agreements can be a more efficient way to meet environmental quality targets than emission taxes, but only if: (1) members of an agreement bear the costs of enforcing compliance with the agreement; (2) there exists member-financed agreements that reach the government's environmental quality target while leaving the members of the agreement at least as well off as they would be under an emissions tax, and (3) the enforcer of a voluntary agreement has significantly better monitoring capabilities or higher sanctions available to it than the government.

Appendix

Proof of Lemma 1: Substitute [9] into [1] to obtain [10].

(*i*) Substitute $s = nt/b$ into $\pi_m^{nc}(s)$ to obtain $\pi_m^{nc}(s = nt/b) = \beta$.

(*ii*) Since $\pi_m^{nc}(s = nt/b) = \beta$ and, from [7], $\pi(t) - e(t)t = \beta + \left((b-t)^2 / 2b''\right)$ it is clear that $\pi_m^{nc}(s = nt/b) < \pi(t) - e(t)t$ under our assumption that $b > t$.

(*iii*) From [10], $\partial\pi_m^{nc} / \partial s = (nt)^2 / s^3 b'' > 0$.

(*iv*) Substitute $s = n$ into $\pi_m^{nc}(s)$ and simplify to obtain $\pi_m^{nc}(s = n) = \beta + \left((b-t)(b+t)/2b''\right)$. Subtract [7] from this to obtain $t(b-t)/b'' > 0$. The sign follows from our assumption that $b > t$.

(*v*) Because $\pi_m^{nc}(s)$ is monotonically increasing in *s*, the largest profit a member of an agreement could earn is $\pi_m^{nc}(s = n) = \beta + \left((b-t)(b+t)/2b''\right)$. From [2], $\pi(e^u) = \beta + \left(b^2 / 2b''\right)$. Subtract $\pi_m^{nc}(s = n)$ from $\pi(e^u)$ to obtain $t^2 / 2b'' > 0$. Therefore $\pi_m^{nc}(s) < \pi(e^u)$ for all *s*. QED.

Proof of Lemma 2: Substituting $e(s, t)$ from [9] into [1] yields $\pi_m^{nc}(s)$ defined in Lemma 1 by equation [10]. Therefore, $\pi_m^{c}(s) = \pi_m^{nc}(s) - x(s)$. Substituting $\pi_m^{nc}(s)$ from [10] and $x(s)$ from [17] yields [18].

i) Since, from [17], $x(s) = nt / s\alpha\bar{f} > 0$, $\pi_m^{c}(s) < \pi_m^{nc}(s)$.

ii) From [18] obtain $\partial\pi_m^{nc}(s) / \partial s = (nt)^2 / s^3 b'' + nt / s^2 \alpha\bar{f} > 0$.

iii) Substitute $s = n$ into [18] and subtract [7] from the result to obtain

$$\pi_m^{c}(s = n) - [\pi(t) - e(t)t] = \left(t/b''\right)\left[(b-t) - b''/\alpha\bar{f}\right].$$

Clearly, $\pi_m^{c}(s = n) \geq \pi(t) - e(t)t$ if and only if $(b-t) \geq b''/\alpha\bar{f}$. Obviously, there exist *s* such that $\pi_m^{c}(s) \geq \pi(t) - e(t)t$ if $(b-t) \geq b''/\alpha\bar{f}$. If $(b-t) < b''/\alpha\bar{f}$, $\pi_m^{c}(s = n) < \pi(t) - e(t)t$. Then, since $\pi_m^{c}(s)$ is increasing in *s*, $\pi_m^{c}(s) < \pi(t) - e(t)t$ for all *s* if $(b-t) < b''/\alpha\bar{f}$. QED.

Proof of Proposition 5: From [28] note that $V^t - V^c$ is monotonically increasing in $\alpha^g \bar{f}^g$. Therefore, given $\alpha \bar{f}$ (with corresponding s^c) and the fact that $V^t > V^c$ when $\alpha \bar{f} = \alpha^g \bar{f}^g$, there exists a value for $\alpha^g \bar{f}^g$ that is strictly less than $\alpha \bar{f}$ at which $V^t = V^c$. This value of $\alpha^g \bar{f}^g$ is

$$\left(\alpha^g \bar{f}^g\right)^0 = \frac{2b'' s^c \alpha \bar{f}}{(n - s^c) t \alpha \bar{f} + 2b'' s^c} \in \left(0, \alpha \bar{f}\right).$$

Given the structure of $V^t - V^c$, $V^t < V^c$ for $\alpha^g \bar{f}^g \in \left(0, \left(\alpha^g \bar{f}^g\right)^0\right)$, while $V^t \geq V^c$ for $\alpha^g \bar{f}^g \geq \left(\alpha^g \bar{f}^g\right)^0$. QED.

Proof of Proposition 6: Recall that a member of a voluntary agreement earns equivalent profits under an emissions tax; that is, $\pi_m^c(s^c) = \pi_m^{nc}(s^{nc}) = \pi(t) - te(t)$. (See Figure 2 to confirm this). Use this relationship and subtract $V^{c/g}$ from V^c to obtain

$$V^c - V^{c/g} = \left(s^c - s^{nc}\right)\left[\pi(t) - te(t) - \pi(e^u)\right] + \frac{nt}{\alpha^g \bar{f}^g}. \qquad [30]$$

Use [3] and [7] to calculate $\pi(t) - te(t) - \pi(e^u) = -t(2b - t)/2b''$. Substitute this along with $s^c - s^{nc}$ from [20] into [30] to obtain

$$V^c - V^{c/g} = -\left[\frac{b'' n + n\sqrt{b''^2 + (\alpha \bar{f})^2 t(2b - t)} - n\alpha \bar{f}\sqrt{t(2b - t)}}{\alpha \bar{f}(2b - t)}\right]\left(\frac{t(2b - t)}{2b''}\right) + \frac{nt}{\alpha^g \bar{f}^g}. \qquad [31]$$

Note that $V^c - V^{c/g}$ is monotonically decreasing in $\alpha^g \bar{f}^g$.

Now let us evaluate $V^c - V^{c/g}$ at $\alpha^g \bar{f}^g = \alpha \bar{f}$. Making this substitution in [31] and simplifying the result yields $V^c - V^{c/g} = Ant/2b''\alpha \bar{f}$, where

$$A = b'' + \alpha \bar{f}\sqrt{t(2b - t)} - \sqrt{b''^2 + (\alpha \bar{f})^2 t(2b - t)}.$$

Clearly, $V^c - V^{c/g} > 0$ at $\alpha^g \bar{f}^g = \alpha \bar{f}$ if and only if $A > 0$, which occurs if

$$b'' + \alpha \bar{f}\sqrt{t(2b - t)} > \sqrt{b''^2 + (\alpha \bar{f})^2 t(2b - t)}. \qquad [32]$$

Since both sides of [32] are strictly positive, we can square them and maintain the inequality. Doing so yields $2b''\alpha \bar{f}\sqrt{t(2b - t)} > 0$. The inequality holds because all the parameters in $2b''\alpha \bar{f}\sqrt{t(2b - t)}$ are positive and $b > t$. Therefore $A > 0$ and $V^c - V^{c/g} > 0$ at $\alpha^g \bar{f}^g = \alpha \bar{f}$.

Thus, when the government and an independent enforcer of a voluntary agreement have the same enforcement capabilities, member-financing of an independent enforcer is more efficient than government enforcement of a voluntary agreement.

However, since $V^c - V^{c/g}$ is monotonically decreasing in $\alpha^g \bar{f}^g$ and is positive at $\alpha^g \bar{f}^g = \alpha \bar{f}$, there exists a unique value of $\alpha^g \bar{f}^g$ that is strictly greater than $\alpha \bar{f}$ at which $V^c - V^{c/g} = 0$. Denote this value as $\left(\alpha^g \bar{f}^g\right)^1$. Clearly, $V^c - V^{c/g} > 0$ if $\alpha^g \bar{f}^g < \left(\alpha^g \bar{f}^g\right)^1$, but $V^c - V^{c/g} < 0$ if $\alpha^g \bar{f}^g > \left(\alpha^g \bar{f}^g\right)^1$.

Finally, we need to show that it is more efficient for the government to impose an emissions tax than to allow a voluntary agreement that it will enforce. Recall that our welfare measure under the emissions tax is $V^t = n\pi(t) - nx(t)$. Substitute $nx(t) = nt / \alpha^g \bar{f}^g$ from [25] into V^t and subtract the result from [29] to obtain:

$$V^t - V^{c/g} = \left[\pi(t) - \pi(e^u)\right]n - \left[\pi(t) - e(t)t - \pi(e^u)\right]s^{nc}.$$

Use [3] and [6] to calculate $\pi(t) - \pi(e^u) = -t^2 / 2b'' < 0$. Then use [5] to calculate $\pi(t) - e(t)t - \pi(e^u) = -t(2b - t)/2b''$. Substitute these into $V^t - V^{c/g}$ to obtain $V^t - V^{c/g} = \left[t(2b-t)s^{nc} - t^2 n\right] / 2b''$, and then use [13] to substitute for s^{nc} to obtain $V^t - V^{c/g} = \left(\sqrt{2b-t} - \sqrt{t}\right)\left(nt^{3/2} / 2b''\right)$. Clearly, $V^t - V^{c/g} > 0$ if and only if $\sqrt{2b-t} > \sqrt{t}$.

Squaring both sides of this last relationship and simplifying yields $b > t$. Since this inequality holds by assumption, $V^t - V^{c/g} > 0$. Thus, it is more efficient for the government to impose the tax than to allow a voluntary agreement that it enforces. QED.

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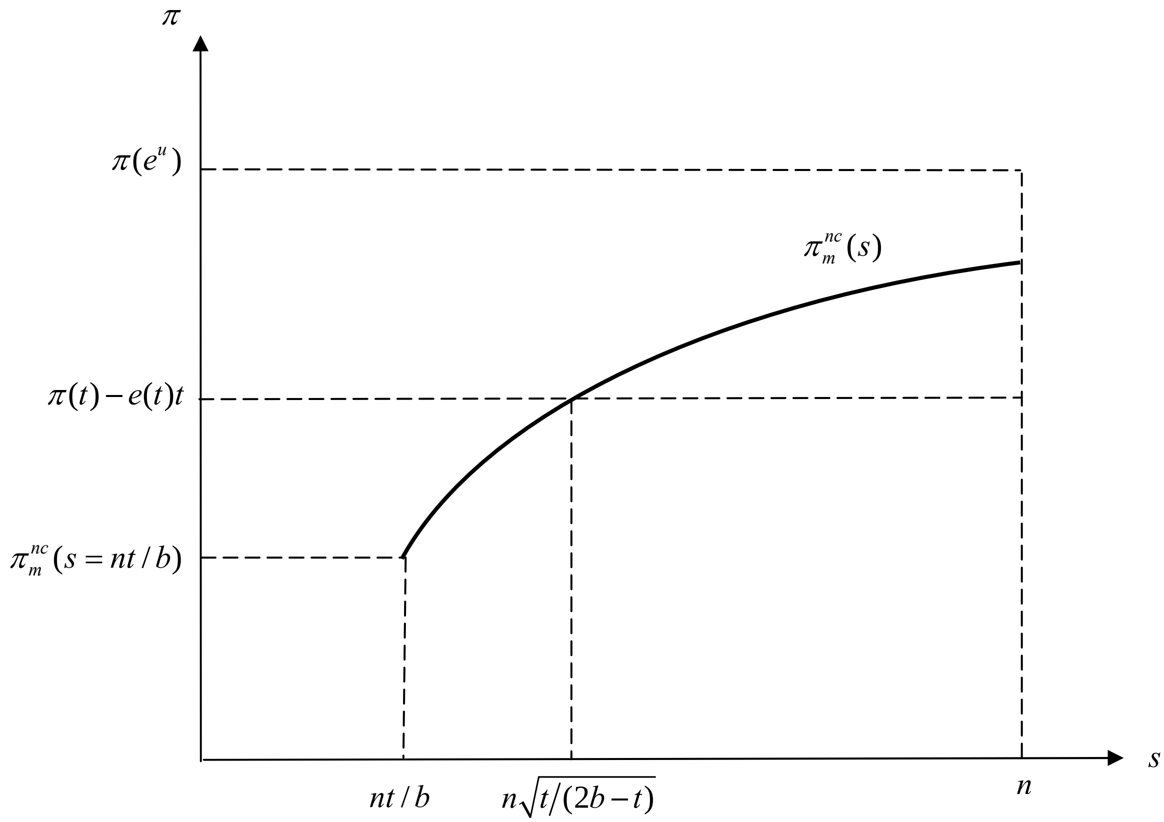

Figure 1: Individual profit under a voluntary environmental agreement that does not require member-financed enforcement and the equilibrium number of members.

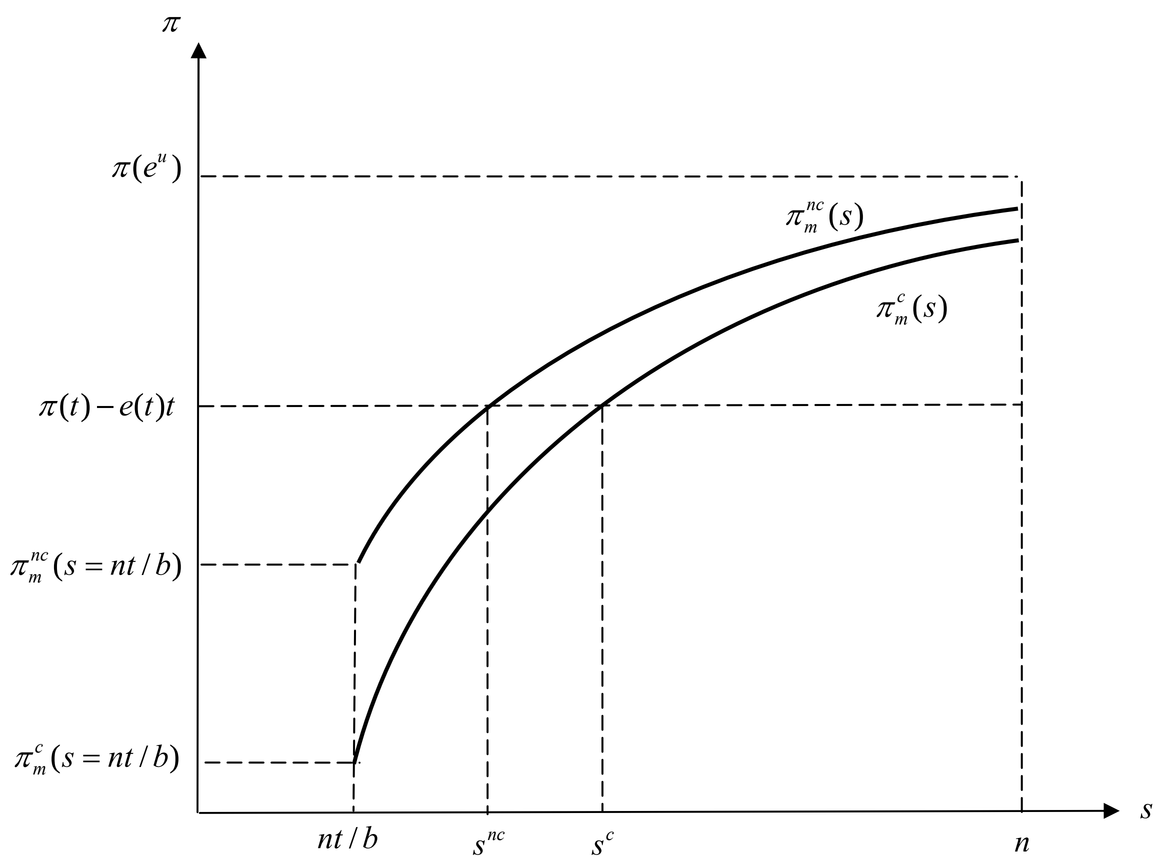

Figure 2: Individual profit under voluntary agreements with member-financed enforcement and the equilibrium number of members when such an agreement forms.