McEvoy, David and John K. Stranlund. (2010). Costly Enforcement of Voluntary Environmental Agreements. *Environmental and Resource Economics,* 47(1): 45-63. Published by Springer www.springer.com (ISSN: 0924-6460). DOI: 10.1007/s10640-010-9364-7.

Costly Enforcement of Voluntary Environmental Agreements

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Abstract

We examine the consequences of costly enforcement on the ability of voluntary agreements with industries to meet regulatory objectives, the levels of industry participation with these agreements, and the relative efficiency of voluntary and regulatory approaches. A voluntary agreement can be more efficient in reaching an aggregate emissions target than a conventional emissions tax, but only if: (1) profitable voluntary agreements in which members of the agreement pay for its enforcement exist; (2) members of a voluntary agreement actually bear the costs of enforcing the agreement; (3) the agreement is enforced by a third party, not the government, and (4) this third-party enforcer has a significant advantage in monitoring technology and/or available sanctions over the government.

Keywords

Emissions tax, Enforcement, Self-enforcing agreement, Voluntary agreements

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. 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 require less time to implement relative to more 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 may be cheaper to enforce than traditional regulations (Bailey 1999; Schmelzer 1999; Nyborg 2000; 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, few studies have rigorously addressed the problem of enforcing voluntary environmental agreements. This paper examines the consequences of enforcement costs and who bears these costs on the ability of voluntary agreements to meet regulatory objectives, the levels of voluntary participation with these agreements, and the relative efficiency of voluntary and an emissions tax.

Voluntary environmental agreements are typically categorized as being one of three forms (Mazurek 1998; Carraro and Leveque 1999; Segerson and Li 1999; Alberini and Segerson 2002; Lyon and Maxwell 2002; Morgenstern and Pizer 2007).*Unilateral agreements* are environmental initiatives developed and implemented by firms or industries without any regulatory involvement. *Public agreements* are agreements in which a regulator sets the requirements and rewards of membership in a program and firms or industries voluntarily decide whether to participate. Under *negotiated agreements*, environmental targets are jointly agreed upon by a regulator and a firm, or between a regulator and industry association. In this paper we focus exclusively on a particular form of negotiated agreement in which a regulator commits to not impose a regulation on an industry (e.g., an emissions tax) if it can voluntarily meet the regulator’s environmental target. This is the most common voluntary approach in Europe (Borkey and Leveque 2000; Conrad 2001). Examples include the Netherland’s Environmental Plan for limiting carbon emissions (i.e., the “Dutch Covenants”), France’s agreement on the treatment of end-of-life vehicles, and the United Kingdom’s Climate Change Agreements.

Compliance with negotiated agreements, like more traditional forms of regulation, must be enforced. This is particularly true when firms’ emissions are not easily observed and the government’s decision to allow a voluntary agreement is not easily reversed. In these cases a firm may be motivated to join an agreement to help prevent the imposition of some conventional regulation, but then decide not to reduce its emissions to the extent required under the agreement. If this occurs, then the environmental goals of the agreement will not be achieved.

Consequently, existing agreements include both monitoring and sanctioning components. Moreover, there is substantial variation in how these agreements are enforced. Some agreements focus on the compliance of individual firms.Monitoring in these agreements may rely on firms submitting self-reports of their emissions or other activities to a third-party or branch association as under the United Kingdom's Climate Change Agreements (Bailey and Rupp 2006), the Netherland's covenants for reducing carbon emissions (Ministry of Economic Affairs 1999), and Chilean agreements on chemical emissions (Jimenez 2007). Given infor mation in self-reports, on-site audits can be conducted by regulators in the UK's Climate Change Agreements or delegated to the firms themselves through a branch association as in the Chilean agreements. Sanctions for individual firm's noncompliance take the form of restrictions on operating licenses under the Dutch covenants, loss of a tax credit in the UK Climate Change Agreements, or a fine from a branch association or other government sanctions in the Chilean case. Other agreements rely on collective monitoring of targets and collective sanctions in cases of industry-wide noncompliance. For example, the German agreement on Global Warming Prevention requires its members, who are major industry associations, to reduce CO2 emissions in exchange for the government's promise to not impose an energy tax. If a member industry is in violation, the government can respond by issuing new regulation, which could include a tax or more traditional command-and-control measures (Borkey and Leveque 2000; Delmas and Terlaak 2002).

Most theoretical analyses of negotiated agreements model simple agreements between a government and a single firm, or a series of independent agreements with an arbitrary number of firms (Segerson andMiceli 1998, 1999; Schmelzer 1999; Nyborg 2000; Lyon and Maxwell 2003; Glachant 2007).3 As a result these studies preclude the possibility of free riding, which is a thought to be an important characteristic of existing voluntary agreements (Storey et al. 1999; Alberini and Segerson 2002). Dawson and Segerson (2008) study the free-riding issue by modeling voluntary participation with an environmental agreement in which a regulator offers an industry the opportunity to meet an aggregate emissions target in exchange for not imposing an emissions tax. They demonstrate that voluntary agreements can always form to 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 emissions control of others, voluntary agreements will not distribute emission control responsibilities efficiently; hence, voluntary agreements can never be as efficient as emissions taxes.

Dawson and Segerson (2008), like most of the literature on voluntary agreements with industries, assume that firms that join an agreement comply with its terms without the need for enforcement. We extend their analysis of the formation and performance of voluntary agreements with industries by adding the missing enforcement component. 4 This is an important extension because several authors have speculated that voluntary agreements may have an advantage over conventional regulation in terms of enforcement. For example, Bailey (1999) suggests that voluntary approaches maybe cheaper to enforce, 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 (Nyborg 2000).

Our approach to modeling enforcement of voluntary agreements is as follows: We've just noted that there is substantial variation in how existing voluntary agreements are enforced. Since we do not focus our work on the choice of enforcement method for voluntary agreements, although we think this may be an important issue for future research, we have chosen to model enforcement of these agreements in a way that is close to what is typically assumed about enforcing an emissions tax. That is, the emissions of individual members of a voluntary agreement are monitored with some endogenous probability and violations are sanctioned with a financial penalty that is proportional to the size of the violation. This allows for a straightforward comparison of the performance of voluntary agreements with that of an emissions tax, without getting tangled up in differences in enforcement methods.

A unique feature of our work is that we address the question of who should enforce voluntary agreements, the government or some third-party, and who should bear the costs of enforcement, the government or the members of the agreement. One does not need to assume that enforcement is unnecessary to obtain Dawson and Segerson's results; they can be obtained under the assumption that an unspecified enforcement method achieves the full compliance of an agreement's members, but these firms do not bear any of the enforcement costs. For comparison, we construct a model in which the members of a voluntary agreement finance and empower a third-party (perhaps a branch association) to enforce the agreement.

Our efforts yield several new insights. First, we demonstrate that enforcement costs that are borne by the members of an agreement limit the circumstances under which voluntary emissions control agreements can form in place of an emissions tax. In fact, agreements with member-financed enforcement will not form when the enforcer of the agreement possesses a weak monitoring technology, the available sanction for noncompliance is too low, or when the aggregate emissions control target to be achieved is too stringent. However, when an agreement with member-financed enforcement forms it will have more members than if members of the agreement did not have to bear the costs of enforcement. Thus, making agreement members bear the costs of enforcement reduces free riding on the agreement. Finally, we show that a voluntary agreement can be an efficient alternative to reaching an aggregate emissions target with a tax, but four conditions must be met: (1) profitable voluntary agreements with member-financed enforcement must exist; (2) members of a voluntary agreement bear the costs of enforcing the agreement; (3) the agreement is enforced by a third-party, not the government, and (4) this third-party enforcer has a significant advantage over the government in its monitoring technology and/or available sanctions.

2 Voluntary Environmental Agreements with Industries
2.1 Fundamentals

Like Dawson and Segerson (2008) we consider an industry of *n* identical firms that emit a uniformly mixed pollutant. Each firm possesses a strictly concave profit function

(1) $$\pi(e) = \beta + be - \left(b''/2\right) e^2,$$

where *β, b* and *b*__ are positive constants and *e* denotes the emissions of each firm. 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 *π _ (e)* = 0, Yielding

(2) $$e^u = b/b''.$$

(The superscript *u* identifies uncontrolled emissions). The firm's profit at this emissions level is

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

Suppose that the government seeks to reduce industry emissions by charging a per unit emissions tax *t*. Assuming full compliance under the tax, each firm chooses its emissions to maximize $\pi(e) - te = \beta + be - \left(b''/2\right) e^2 - te,$, resulting in individual emissions

(4) $$e(t) = (b - t)/b''.$$

Throughout the analysis we consider taxes such that 0 < *t* < *b*. These restrictions focus the analysis on situations in which the government wishes to reduce the industry's emissions, but not all the way to zero. Substituting (4) into (1) gives us each firm's gross profit under the tax:

(5) $$\pi(e(t)) = \beta + (b - t)(b + t)/2b''.$$

Subtracting the tax payment from (5) yields each firm's net profit:

(6) $$\pi(e(t)) - e(t)t = \beta + (b - t)^2/2b''.$$

An 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^n*. However, suppose the government is willing not to impose the emissions tax if the industry can reach *ne(t)* through a voluntary emissions control agreement. Dawson and Segerson (2008) model such an agreement. In their model member firms commit to emissions standards that satisfy the government’s target, taking into account the emissions choices of the nonmember firms. In response, the government does not impose the emissions tax. The main results of Dawson and Segerson (2008) are that an aggregate emission target can always be achieved with a voluntary agreement, but such an agreement will generally involve only a subset of firms who control their emissions while the remaining firms do not. Consequently, voluntary emissions control agreements with industries can meet regulatory objectives, but they will not distribute individual emissions control efficiently.

Although Dawson and Segerson assumed away problems of enforcing voluntary agreements, one way to think about enforcement in their model is that the government only measures aggregate emissions (and does so perfectly), and if its target is exceeded it simply imposes the emissions tax on all firms. All members of an agreement would comply because each of them knows that if they fail to meet their individual emissions standard, the aggregate target will not be achieved, the regulator will observe this, and it will impose the emissions tax.

In more realistic cases it will not be easy to monitor aggregate emissions from an industry without monitoring individual firms.Moreover, a government’s decision to allow a voluntary agreement in place of a tax may not be easy to reverse. This could be because implementing an emissions control policy (whether a conventional regulation or a voluntary agreement) is so time consuming and costly that it is hard for the government to reverse itself. (Glachant (2007) discusses the difficulties of enacting new legislation). The combination of hard-to-reverse regulatory decisions and hard-to-observe aggregate emissions implies that in many cases it will not be possible to enforce a voluntary agreement by threatening to impose a tax in case of aggregate noncompliance.

Therefore, we assume that a regulator’s decision to allow a voluntary agreement or to impose a tax cannot be reversed, and that determining compliance with an agreement is based on imperfect and costly measures of member firms’ emissions. Moreover, sanctions for noncompliance are financial penalties that are linear in the size of a member firms’ violation.

Another way to think about enforcement in Dawson and Segerson’s model is that their results obtain under the assumption that the government bears the costs of enforcing an agreement and enforcement is successful in making sure that all member firms are compliant. It turns out that who bears the responsibility for enforcing a voluntary agreement and who bears the enforcement costs have a significant impact on the performance of voluntary agreements. This variation requires that we present a model of the formation of a voluntary emissions control agreement in which members of a voluntary agreement finance a third-party enforcer to monitor their compliance behavior and to apply sanctions in cases of noncompliance.

2.2 Voluntary Agreements with Member-Financed Enforcement

Participation and compliance with a voluntary agreement is modeled in four stages. In the first stage (*membership stage*) firms freely choose whether they will become a member of an agreement. In stage two (*agreement stage*), member firms jointly agree on whether to reduce their emissions to a standard that meets the government's aggregate target, given the emissions of the nonmember firms. If the members agree to meet the target, each of them contributes funds to the enforcer to maintain their compliance with the 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 low participation), they do not fund the enforcer, an effective agreement does not form, and the government imposes the emissions tax. (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 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. Because the game is solved by backward induction, we start with the last stage.

2.2.1 Enforcement Stage

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. 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 third-party enforcer randomly audits the emissions of the agreement members and applies a sanction in cases of noncompliance.

Monitoring by the enforcer consists of $a \leq s$ random audits of the agreement members. An audit of a firm reveals its emissions 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

(7) $$\rho = a/s = \alpha x.$$

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 standard required under the agreement. Let *em(s)* denote the emissions standard for each member of an agreement with *s* members. The exact standard will be specified shortly. If the enforcer finds a violator it imposes a unit fine of *f* on *e* − *em(s)* > 0. Note that each firm faces the expected marginal penalty *ρ f* = *αx f.* The fine is constrained to be no more than an exogenous value *f*.

2.2.2 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 the agreement members and nonmembers independently choose their emissions. Nonmembers have no incentive to control their emissions, so they each choose their uncontrolled levels *eu* specified by (2). Member firms, however, hold their emissions to *em(s)* 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.

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 π(e)* − *ρ f (e* − *em(s)),* subject to *e* ≥ *em(s)* where *π(e)* is specified in (1). The Kuhn-Tucker conditions for a solution to this problem are *π* _ *(e)* − *ρ f* ≤ 0*, e* − *em(s)* ≥ 0, and [*π* _ *(e)*−*ρ f*][*e*−*em(s)*] = 0*.* These conditions indicate that all parties will comply with the standard as long as

(8) $$\rho f \geq \pi'(e_m(s)).$$

Thus a firm will comply as long as the expected marginal penalty for violating the standard is not less than its marginal profit evaluated at the standard. This guarantees that a firm's marginal benefit from noncompliance—*π' (e)* for *e* ≥ *em(s)*—is never greater than the expected marginal penalty. In the previous stage of the game, the agreement stage, the members of an agreement will provide sufficient funds to the enforcer to guarantee that (8) holds.

2.2.3 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 of the agreement stage as long as these decisions maximize their joint profits. 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 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.

With s member firms, each of which emit $em(s)$, and $n - s$ nonmembers each of which emit eu, the government's aggregate emissions target is achieved if and only if $sem(s) + (n - s)eu \leq ne(t)$. The uniform emissions standard required of each member of a voluntary agreement is determined by substituting $e(t) = (b - t)/b$__ and $eu = b/b$__ from (4) and (2) into $sem(s) + (n - s)eu = ne(t)$ and solving for $em(s)$:

(9) $$e_m(s) = (sb - nt)/sb''.$$

Note that $em(s) \geq 0$ 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 $em(s)$ is increasing in s, but is decreasing in t. 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 emissions further to achieve the government's goal.

To determine the payment each member of an effective voluntary agreement makes to the enforcer, note that agreement members will contribute just enough to the enforcer so that it can maintain compliance with minimum monitoring costs. From (8) this requires $\rho f = \pi'(em(s))$, yielding the audit probability $\rho = \pi'(em(s))/f$. Use (1) and (9) to calculate $\pi'(em(s))$ and substitute the result into $\rho = \pi'(em(s))/f$ to obtain $\rho = nt/sf$. Since this is decreasing in the fine, the agreement members will all agree that the fine should be as high as possible; that is, $f = f$. Therefore, minimal monitoring to maintain compliance requires

(10) $$\rho = nt/s\bar{f}.$$

Since we must have $\rho \leq 1$, it is clear that $s \geq nt/f$ 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 a low sanction and lack of participation can prevent the formation of a voluntary agreement. For the remainder of this analysis we assume that $nt \leq s\bar{f}$ to allow an effective agreement to form. Given that an agreement forms, the payment each member of the agreement makes to the enforcer is determined by combining (10) and (7) to obtain

(11) $$x_m(s) = nt/s\alpha\bar{f}.$$

Not surprisingly, ρ and $xm(s)$ are decreasing in the fine and the productivity of monitoring resources. More interestingly, they are also decreasing in the number of members of the agreement. That $\pi'(em(s))$ is 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 and the payment each member makes to the enforcer can be reduced. On the other hand, an increase in the threatened tax implies that the government's aggregate target is lower and members of the agreement must reduce their emissions further. Since firms have a greater incentive to violate a lower standard, the audit probability required to maintain their compliance and the payment they make to the enforcer must increase as the emissions tax is increased.

2.2.4 Membership Stage

Members of a voluntary agreement will agree to an 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 shortly; for now, let us just say that profitability depends on the number of firms that join the agreement in the first stage of the game (the membership stage). If a sufficient number of firms join 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 standard. In the fourth stage the enforcer conducts 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.

Having laid out all the elements of a voluntary agreement with member-financed enforcement, we now turn to determining the equilibrium of the game.

3 Equilibrium Voluntary Environmental Agreements

Recall that an effective voluntary agreement is one that leads to voluntary achievement of the aggregate emissions target in place of an emissions tax. To determine the equilibrium number of members of an effective agreement, like Dawson and Segerson, we adopt the concept of a self-enforcing agreement that has been used in the study of cartels (D'Aspremont et al. 1983), and international environmental agreements (Barrett 1994; Kolstad 2007). For an agreement to be self-enforcing, it must satisfy three conditions: (1) it must be profitable in the sense that each member of the agreement is at least as well off in the agreement as under the emissions tax; (2) it must be internally stable in the sense that no member of an agreement is motivated to leave it, and (3) it must be externally stable in the sense that no nonmember wishes to join a voluntary agreement. We begin by examining the profitability requirement of voluntary agreements that require member-financed enforcement.

3.1 Profitable Voluntary Agreements with Member-Financed Enforcement

From Sect. 2.2.3, recall that the members of an agreement cannot meet the regulator's emissions target if $s < nt/b$. Moreover, recall from (10) and the discussion that followed that the enforcer of an agreement would not be able to maintain compliance with the agreement if $s < nt/\bar{f}$. Thus, an effective voluntary agreement cannot form if s < max (nt / b, nt / f). To focus on situations in which an effective agreement with member-financed enforcement can actually form, we limit our analysis to agreements such that $s \in \left[\max\left(nt/b, nt/f\right), n\right]$.

Let $\pi_m^c(s)$ denote the profit of each member of an agreement. (The superscript *c* indicates profit for members of an agreement when they bear the costs of enforcing it). To compare outcomes with and without member-financed enforcement, let $\pi_m^{nc}(s)$ denote the profit of each member of an agreement that does not require member-financed enforcement. (The superscript *nc* indicates profit levels for firms in voluntary agreements that do not require member-financed enforcement). The following lemma specifies $\pi_m^c(s)$ and states some of its characteristics. It is proved in the appendix.

Lemma 1 *For s* ∈ [max (*nt/b, nt/* $\bar{f}$) *, n*]*, the profit for each firm in a voluntary emissions control agreement that requires member-financed enforcement is*

(12)
$$\pi_m^c(s) = \pi(e_m(s)) - x_m(s) = \pi_m^{nc}(s) - x_m(s) = \beta + \frac{(sb)^2 - (nt)^2}{2s^2b''} - \frac{nt}{s\alpha\bar{f}},$$

with the following characteristics:

(*i*) $\partial\pi_m^c(s)/\partial s > 0$ *and* $\partial\pi_m^{nc}(s)/\partial s > 0$;
(*ii*) *there exist* $s > 0$ *such that* $\pi_m^{nc}(s) \geq \pi(e(t)) - e(t)t$;
(*iii*) *there exist* $s > 0$ *such that* $\pi_m^c(s) \geq \pi(e(t)) - e(t)t$ *if and only if* $(b - t) \geq b''/\alpha\bar{f}$.

For a given *s*, (12) indicates that 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, $x_m(s)$. Part (*i*) of the lemma indicates that the profit of each member of an agreement with and without member-financed enforcement is increasing in the number of members. Parts (*ii*) and (*iii*) are more interesting because they reveal when profitable agreements exist. Part (*ii*) is a restatement of Dawson and Segerson's result that profitable voluntary agreements without member-financed enforcement always exist. (This result follows from the assumption that $b > t$). However, part (*iii*) indicates that profitable agreements with member-financed enforcement exist only if $(b - t) \geq b''/\alpha\bar{f}$. There is nothing in the model with member-financed enforcement that requires or implies this condition. Since only profitable agreements can form in place of an emissions tax, we have our first conclusion about the impact of member-financed enforcement on voluntary emissions control agreements.

Proposition 1 *Profitable voluntary agreements with member-financed enforcement exist if and only if (b − t)* $\geq b''/\alpha\bar{f}$. *Thus, the circumstances under which an effective voluntary 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 how member-financed agreements can fail to form. Somewhat 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 $\bar{f}$, are 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. Moreover, the likelihood that an agreement can form falls as the threatened emissions tax is increased. Since the government's aggregate emission target is decreasing in *t*, voluntary agreements with member-financed enforcement can fail to form if the government's aggregate environmental target is too stringent.

3.2 A Self-Enforcing Voluntary Agreement that Requires Member-Financed Enforcement

It is well-known that the minimum size profitable coalition is critical in determining the self-enforcing number of participants with a voluntary agreement. When profitable agreements with member-financed enforcement exist the smallest profitable coalition is:

(13)
$$s^c_{\min} = s\,|\left[\pi^c_m(s) = \pi(e(t)) - e(t)t\right] = \frac{nb'' + n\sqrt{b''^2 + \left(\alpha\bar{f}\right)^2(2b-t)t}}{\alpha\bar{f}(2b-t)}.$$

Let *sc* be the equilibrium number of members of a self-enforcing voluntary emission control agreement that requires member-financed enforcement. The definition of a *self-enforcing voluntary agreement* in this setting is:

Definition Suppose that *(b − t)* $\geq b''/\alpha\bar{f}$ so that profitable voluntary agreements with member-financed enforcement exist. An agreement with *s^c* > 0 firms is self-enforcing if and only if:

(14)
$$\text{(i)}\quad \pi^c_m(s^c) \geq \pi(e^u) \text{ for } s^c > s^c_{\min},\ \text{ or } \pi^c_m(s^c) \geq \pi(e(t)) - e(t)t \text{ if } s^c = s^c_{\min};$$
$$\text{(ii)}\quad \pi(e^u) \geq \pi^c_m(s^c+1).$$

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. The only internally and externally stable coalition size is the smallest profitable coalition, provided that a profitable coalition actually exists. Therefore, we have:

Proposition 2 *A self-enforcing voluntary emissions control agreement with member-financed enforcement has sc = sc* min *members 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.*

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. In Fig. 1 we have graphed a candidate for *πcm(s)* that allows an agreement with member-financed enforcement to form.9 Figure 1 clearly illustrates that all coalitions involving memberships greater than or equal to *sc* min are profitable. To see why the only self-enforcing number of members of a voluntary agreement is *sc* min, note first that if *sc* > *sc* min, then at least one member of *sc* could leave the agreement to earn the free-riding payoff, $\pi(e^u) > \pi_m^c(s)$, without having the agreement collapse. Thus, no coalitions with more than *sc* min members are internally stable. However, a coalition with exactly *sc* min 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 voluntarily and the tax would be imposed on all firms. Finally, an agreement with *sc* = *sc* min members is externally stable: no nonmember would join this agreement because they earn more by free riding.

If the members of a voluntary agreement do not bear the costs of enforcing the agreement, (11) and (12) indicate that they each earn profit of

$$\pi_m^{nc}(s) = \beta + \frac{(sb)^2 - (nt)^2}{2s^2 b''}.$$

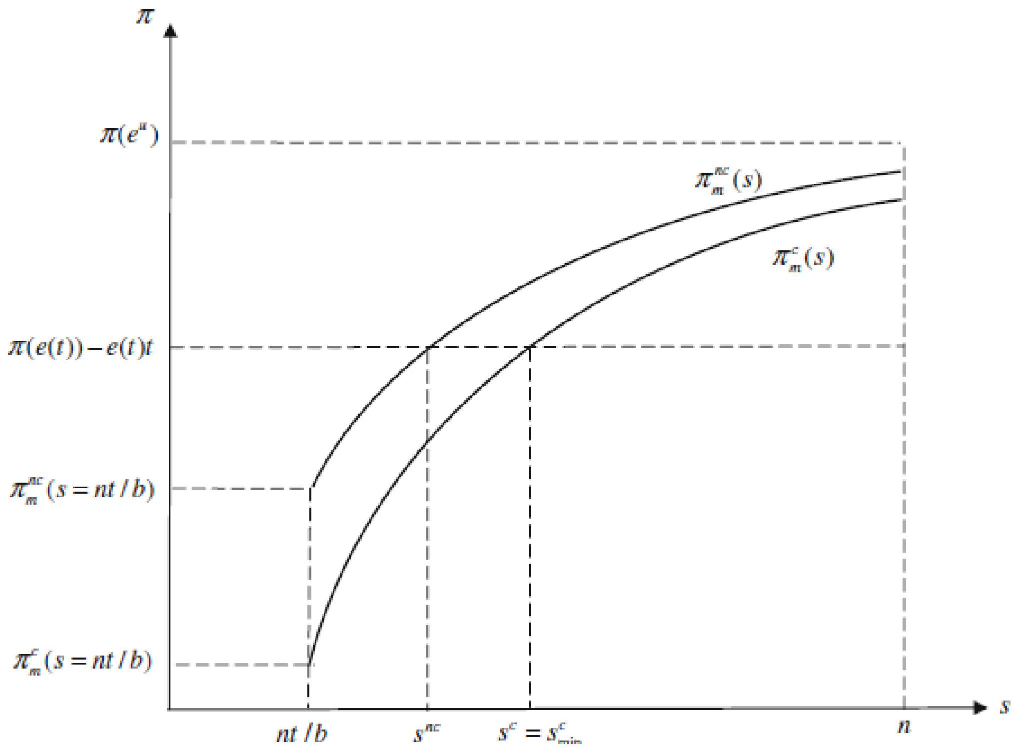

Fig. 1 Individual profit under voluntary agreements with and without member-financed enforcement and the equilibrium number of members

This is also graphed in Fig. 1. It is always above $\pi_m^c(s)$, because $\pi_m^c(s) = \pi_m^{nc}(s) - x_m(s)$ from Lemma 1. Moreover, recall that part (*ii*) of Lemma 1 guarantees that profitable agreements always exist when members do not bear the enforcement costs. Let *snc* denote the equilibrium number of members to an agreement that does not require member-financed enforcement. This is the equilibrium of Dawson and Segerson. As always the equilibrium number of members of a voluntary agreement is the smallest profitable coalition, which is *s* such that $\pi_m^{nc}(s) = \pi(e(t)) - e(t)t$. Using (6) to solve this equation for *s* yields

(15) $$s^{nc} = n\sqrt{t(2b-t)}$$

as the equilibrium coalition size when the coalition members do not bear the enforcement costs.

It is clear from Fig. 1 that *sc* > *snc*. More formally, subtract (15) from (13) to obtain:

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

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

Proposition 3 *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.

When a voluntary agreement with member-financed enforcement forms the number of free riders on the agreement will be less than if the agreement members did not bear enforcement costs. Recall that Dawson and Segerson (2008) 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 how does having agreement members finance enforcement change total enforcement costs? It turns out that the total costs of enforcing an effective agreement with member-financed enforcement are exactly the same as the costs of enforcing an agreement without member-financed enforcement, even though the size of the agreements are different. To see this suppose that the entity that enforces the agreement has a monitoring parameter α and a sanction $\bar{f}$. Then, (11) gives us the per-firm cost of enforcing the emissions standard of an agreement with *s* members, and total enforcement costs are $sx_m(s) = nt/\alpha\bar{f}$. That this is independent of *s* tells us that the total enforcement costs of an agreement with member-financed enforcement are the same as if the agreement members did not finance its enforcement. There are two equal but opposing forces at work here. An agreement with member-financed enforcement has more members, which increases the costs of enforcement. However, more members means that the individual emissions standard is higher, which reduces enforcement costs because firms have a lower incentive to violation a less stringent standard. In our model these effects exactly offset each other.

Since having agreement members incur enforcement costs reduces free-riding loss, but does not change total enforcement costs for a particular monitoring technology and sanction, we have the following proposition.

Proposition 4 *Given a monitoring technology and sanction applied to a voluntary agreement, if an effective agreement with member-financed enforcement forms, it will be more efficient than if agreement members did not bear the costs of enforcement.*

Our results thus far reveal the importance of having the members of an agreement finance its enforcement: if an effective voluntary agreement with member-financed enforcement can form, it will be more efficient than an agreement that has some other entity (like the government) bear its enforcement costs. The question now becomes, is it ever possible for a voluntary agreement to be more efficient than an emissions tax? Absent a consideration of enforcement costs, this is not possible as Dawson and Segerson show. However, in the next section we show that considering enforcement costs yields a limited set of circumstances under which a voluntary agreement can be an efficient alternative to an emissions tax.

4 Enforcement Costs and the Relative Efficiency of Voluntary Environmental Agreements

4.1 The Cost of Enforcing an Emissions Tax

To compare the efficiency of a voluntary agreement and an emissions tax, we first need to derive the cost of enforcing a tax. Under a tax each firm in the industry is 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 ρg. (The superscript g identifies parameters and variables associated with the government's enforcement capabilities. In general, these will be different from those of a third-party enforcer of a voluntary agreement). If a firm is audited and their reported emissions are lower than their actual emissions, the firm is fined $f^g \leq \bar{f}^g$ per unit of $e - r > 0$. As with the enforcement of a voluntary agreement, we assume that the government enforces the emissions tax so that all firms are compliant.

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

(17) $$\pi(e) - tr - \rho^g f^g (e - r), \text{ s.t. } e \geq r \geq 0.$$

The constraint $e - r \geq 0$ is imposed because a firm will never have an incentive to over-report its emissions. Let L denote the Lagrange equation for (17) and let λ denote the multiplier attached to the constraint $e - r \geq 0$. Then, the following first-order conditions are both necessary and sufficient to determine the firm's choices of emissions and emissions report:

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

(19) $$\mathcal{L}_r = -t + \rho^g f^g - \lambda \leq 0, r \geq 0, r(t - \rho^g f^g - \lambda) = 0;$$

(20) $$\mathcal{L}_\lambda = e - r \geq 0, \lambda \geq 0, \lambda(e - r) = 0.$$

Under the assumption that a firm will comply if it is indifferent between compliance and noncompliance, (19) and (20) reveal that inducing truthful reporting requires that the tax not exceed the expected marginal penalty for under-reported emissions; that is, $t \leq \rho^g f^g$. 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 cost of inducing full compliance the government sets the fine at its maximum level, $f^g = \bar{f}^g$, and monitors so that $t = \rho^g \bar{f}^g$.11 Finally, since $r = e > 0$, (19) becomes $L_r = 0$. Then, combining (18) and (19) 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 (6).

In enforcing the emission tax the government has the same sort of linear monitoring technology as the third-party enforcer of an alternative voluntary agreement with member-financed enforcement. 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 $t = \rho^g \bar{f}^g$, the per-firm cost of enforcing the emissions tax is $x(t) = t/\alpha^g \bar{f}^g$, and aggregate enforcement costs are

(21) $$nx(t) = nt/\alpha^g \bar{f}^g.$$

4.2 Can a Voluntary Emissions Control Agreement be More Efficient than an Emissions Tax?

Our welfare measure under the emissions tax is aggregate gross industry profit less the aggregate costs of enforcement, $V^t = n\pi(e(t)) - nx(t)$. 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 industry profit, $V^c = \pi^c_m(s^c)s^c + \pi(e^u)(n - s^c)$. Recall from (12) that $\pi^c_m(s^c)$ includes the payment a member of a voluntary agreement makes to the enforcer of the agreement; hence, V^c includes the total costs of enforcing an agreement. The difference between welfare under the emissions tax and the voluntary agreement is $V^t - V^c = n\pi(e(t)) - nx(t) - [\pi^c_m(s^c)s^c + \pi(e^u)(n - s^c)]$. Upon substitution of $\pi(e(t))$ from (5), $nx(t)$ from (21), s^c from Proposition 2, $\pi^c_m(s)$ from (12), and $\pi(e^u)$ from (3), we have:

(22) $$V^t - V^c = \frac{nt(n - s^c)}{2b'' s^c} + \frac{nt}{\alpha \bar{f}} - \frac{nt}{\alpha^g \bar{f}^g}.$$

Note that the second and third terms of (22) capture the difference between the costs of enforcing the voluntary agreement and the costs of enforcing the emissions tax (see (11) and (21)). 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 (22) reveals clearly that $V^t > V^c$ if $\alpha \bar{f} = \alpha^g \bar{f}^g$ and $n > s^c$. Just as clearly, if the government has the enforcement advantage so that $\alpha \bar{f} < \alpha^g \bar{f}^g$, then a voluntary agreement with member-financed enforcement will never be more efficient than an emissions tax. However, our next proposition reveals that if an agreement with member-financed enforcement can form, it is *always possible* that the third-party enforcer of the agreement has enough of an advantage over the government to make a voluntary agreement more efficient than an emissions tax. 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* $\alpha^g \bar{f}^g < (\alpha^g \bar{f}^g)^0$*, where* $(\alpha^g \bar{f}^g)^0$ *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 in Proposition 5, $(\alpha^g \bar{f}^g)^0$, 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 $(\alpha^g \bar{f}^g)^0$. 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.

Of course, another possibility for the design of a voluntary agreement is for the government to do the enforcement. If the government enforces a voluntary agreement, then either it bears the enforcement costs or it recovers the costs from the members of the agreement. In the former case the number of members of the agreement is s^{nc} (defined by (15)) and in the latter case the number of members is s^c (defined by (13) and Proposition 2) with $\alpha \bar{f}$ replaced by $\alpha^g \bar{f}^g$. From (11), if the government enforces a voluntary agreement with s members, the per-member firm cost of enforcement is $x_m(s) = nt/s\alpha^g \bar{f}^g$. We have demonstrated that total enforcement costs of voluntary agreements with and without member-financed enforcement are the same, provided that the enforcement technologies are the same. Therefore, the total costs of the government enforcing a voluntary agreement when it covers these costs and when it charges the agreement members are $s^{nc}x_m(s^{nc}) = s^c x_m(s^c) \quad = nt/\alpha^g \bar{f}^g$. Compare this to (21) to note that the total costs of enforcing the emissions tax is equal to $s^{nc}x_m(s^{nc})$ and $s^c x_m(s^c)$ as well. Our following proposition follows directly from the fact that there is a freeriding loss with voluntary agreements and the government cannot conserve enforcement costs by allowing a voluntary agreement that it enforces.

Proposition 6 *It is always more efficient for the government to impose the emissions tax than to allow a voluntary agreement that it enforces.*

We now have all the ingredients necessary to prove our final proposition, which reveals that voluntary emissions control agreements can be an efficient alternative to an emissions tax, but only under a fairly limited set of circumstances.

Proposition 7 *A voluntary agreement is an efficient alternative to reaching an aggregate emissions target with an emissions tax if and only if: (1) profitable agreements with member-financed enforcement exist; (2) members of a voluntary agreement bear the costs of enforcing the agreement; (3) the agreement is enforced by a third-party, not the government, and (4) this third-party enforcer has a significant advantage in monitoring technology and/or available sanctions over the government.*

5 Conclusion

Our efforts have provided several new results that have significant relevance for our understanding of the efficacy and efficiency of voluntary emissions control agreements. Our most important result is Proposition 7, because it suggests that voluntary agreements can be more efficient than an emissions tax, if only under a limited set of circumstances. This is an important contribution to the literature, because Dawson and Segerson conclude that voluntary agreements with industries can never outperform an emissions tax. Adding the enforcement component to the analysis of the formation of voluntary agreements, and analyzing issues related to who should enforce these agreements and who should bear their enforcement costs, has revealed an avenue through which voluntary agreements may outperform emissions taxes.

Toward setting out the conditions under which voluntary agreements can be efficient, we discovered that the opportunities for a voluntary agreement to form are limited when agreement members are responsible for paying enforcement costs. This is an important finding for several reasons. First, it is contrary to Dawson and Segerson's finding that a voluntary agreement can always form to reach a regulator's environmental target. Second, the analysis suggests that weak monitoring capabilities, a low sanction, or a stringent environmental target are all possible reasons why a voluntary agreement with member-financed enforcement may not be viable.

Moreover, a voluntary agreement is more efficient if its members bear the costs of its enforcement. We show that if an agreement with member-financed enforcement does form it will have more members than an agreement that does not require member-financed enforcement. Thus, requiring members to bear the enforcement costs of the agreement reduces free riding loss. Shifting these costs to another entity (say the government) does not lower total enforcement costs, but does increase the free riding loss. Thus, if a voluntary agreement is to be an efficient alternative to an emissions tax, the members of the agreement must bear its costs.

We also show that a government regulator should not take on the responsibility of enforcing a voluntary agreement or the costs of enforcement: an emissions tax is always more efficient than a voluntary agreement that the government enforces, and we've noted several times that members of an agreement should take on its enforcement costs. A voluntary agreement can be more efficient than a tax only if a third-party enforces it. We demonstrate one final requirement for a voluntary agreement to outperform an emissions tax: the enforcer of the agreement must have a significant advantage over the government in terms of its ability to monitor firms' compliance and/or in terms of the sanction it can apply in cases of noncompliance.

We have focused our analysis on how the distribution of enforcement responsibilities and enforcement costs affect the efficiency of voluntary agreements with industries, without attempting to analyze alternative methods of enforcing these agreements. To make our analysis as straightforward as possible, we assumed that the method of enforcing agreements is close to what we assume about enforcing emissions taxes. Yet, recall from the introduction that there is substantial variation in how existing agreements are enforced. One may wonder how our results would hold up if the method of enforcing a voluntary agreement was assumed to be different than the method of enforcing an emissions tax. For example, we noted that some voluntary agreements in Europe are based on the aggregate performance of an industry, monitoring is of industry performance, and threatened sanctions are collective punishments in which the regulator sanctions all firms if the industry fails to meet its target.

Under this sort of collective enforcement of a voluntary agreement, the principles contained in Proposition 7 are likely to hold, with perhaps some modifications. Our work suggests that it is always more efficient for members of a voluntary agreement to bear its enforcement costs, whatever the enforcement method. Thus, it is important to recognize that profitable voluntary agreements with member-financed collective enforcement may not exist. Moreover, the existence of profitable agreements will turn on the effectiveness of the monitoring technology, the available sanction, and the stringency of the government's environmental target. In contrast to Proposition 7, it may be efficient for the government to take on the enforcement of a voluntary agreement, but this is only true if it can employ a method of enforcement (i.e., collective enforcement) that is different from how it enforces an emissions tax. Finally, it is likely that a voluntary agreement with collective enforcement can be an efficient alternative to an emissions tax, but only if collective enforcement is substantially cheaper than enforcing an emissions tax. It may be a worthwhile endeavor for future research to confirm or disprove these assertions.

Appendix

Proof of Lemma 1 Substituting $e_m(s)$ from (9) into (1) yields $\pi_m^{nc}(s) = \beta + \left((sb)^2 - (nt)^2\right) / 2s^2 b''$. Subtract (11) from $\pi_m^{nc}(s)$ to obtain (12).

(*i*) $\partial \pi_m^{nc} / \partial s = (nt)^2 / s^3 b'' > 0$ and $\partial \pi_m^c(s) / \partial s = (nt)^2 / s^3 b'' + nt / s^2 \alpha \bar{f} > 0$.

(*ii*) Since $\pi_m^{nc}(s = nt/b) = \beta$ and, from (6), $\pi(e(t)) - e(t)t = \beta + \left((b-t)^2 / 2b''\right)$ it is clear that $\pi_m^{nc}(s = nt/b) < \pi(e(t)) - e(t)t$.

(*iii*) Since $\pi_m^c(s)$ is increasing in s, there exist s such that $\pi_m^c(s) \geq \pi(e(t)) - e(t)t$ if and only if $\pi_m^c(s = n) \geq \pi(e(t)) - e(t)t$. Substitute $s = n$ into (12) and subtract (6) from the result to obtain

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

Clearly, $\pi_m^c(s = n) \geq \pi(e(t)) - e(t)t$ if and only if $(b - t) \geq b''/\alpha \bar{f}$. Therefore, there exist s such that $\pi_m^c(s) \geq \pi(e(t)) - e(t)t$ if and only if $(b - t) \geq b''/\alpha \bar{f}$.

Proof of Proposition 5 From (22) 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 $\alpha^g \bar{f}^g \geq \left(\alpha^g \bar{f}^g\right)^0$.

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