Voluntary Agreements with Industries: Participation Incentives with Industry-Wide Targets

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ABSTRACT. *We consider a policy environment in which an entire industry is faced with possible imposition of an emissions tax if environmental goals are not met voluntarily. We develop a multiple-firm model of pollution abatement in this context. Using the concept of a self-enforcing equilibrium, we examine the free-riding incentive of individual firms and its impact on the viability of the voluntary approach. We find that, despite the free-riding problem, a sub-group of firms have an incentive to participate in the VA. The VA is strictly preferred by the industry as a whole, although it is not cost-minimizing.* (JEL Q53, Q58)

I. INTRODUCTION

Since the early 1970s, policymakers have relied heavily on regulation as a means of controlling the emissions of environmental pollutants. These regulations have been widely criticized for being costly and inefficient. In response, policymakers have begun to search for alternative policies that allow environmental protection goals to be met at lower cost. One alternative is to move toward the use of incentive or market-based policy instruments, such as emission taxes or marketable permits. Another alternative that has attracted policymakers' attention is increased reliance on voluntary environmental protection.[1] Since the early 1990s, hundreds of voluntary agreements (VAs) have been signed throughout the world, many of them in the European Community (see Commission of the European Communities (CEC) 1996; European Environmental Agency (EEA) 1997; Organisation for Economic Co-operation and Development (OECD) 1999).

While many voluntary agreements are between regulators and individual firms,[2] often an agreement takes the form of an explicit or implicit agreement between regulators and a group of firms or an industry. Examples include the French agreement on the treatment of End-of-Life Vehicles (ELV) (Lévêque and Nadaï 1995; EEA 1997; Aggeri and Hatchuel 1999), the Norwegian waste agreements (Nyborg 2000), and the German industry and trade associations' voluntary declaration on CO_2 reduction (Lévêque and Nadaï 1995; EEA 1997; Jochem and Eichhammer 1999).

To be successful, a voluntary approach must have a sufficiently strong incentive for firm participation, that is, firms must in some way benefit from undertaking voluntary measures. Firms can benefit from adopting voluntary measures if a proactive environmental strategy allows them to exploit a market for environmentally friendly products or generate firm-specific public goodwill (Smart 1992; Arora and Gangopadhyay 1995; Esty 1997; Khanna and Damon 1999). Alternatively, firms might voluntarily undertake pollution

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[1] Voluntary approaches to environmental protection can take three forms: (1) unilateral environmental initiatives by firms and industry associations ("corporate environmentalism"); (2) negotiated agreements between government agents and firms or industry associations; and (3) environmental programs designed by government agents to induce voluntary participation (Carraro and Lévêque 1999; Segerson and Li 1999).

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[2] Examples include Project XL in the United States (Davies and Mazurek 1996), and the many agreements negotiated under the Dutch National Environmental Policy Plan (CEC 1996).

abatement if, by adopting voluntary measures, they can avoid more costly government policies that might be imposed. If the threatened government policy is a regulation with limited flexibility, firms can benefit from the increased flexibility that might accompany a voluntary approach.[3] If the threatened policy is an emissions tax, firms can benefit by avoiding the tax payments. For example, the voluntary agreements involving the German energy sector were prompted by threats of imposition of a carbon tax (EEA 1997; Jochem and Eichhammer 1999). Similarly, voluntary agreements in Norway resulted from threats regarding imposition of a tax on packaging materials (Nyborg 2000).

While threats of the imposition of regulation or emissions taxes can be effective in providing participation incentives, when applied to an entire industry they suffer from a potentially serious drawback, namely, the incentive for individual firms to free-ride. If the industry can avoid the regulation or tax with less than full participation, then firms that do not participate can enjoy the benefits of avoiding the costly policy without the associated costs. Although some have argued that industry associations will find means to solve the free-rider problem (e.g., Nyborg 2000), a survey of voluntary approaches by the European Environmental Agency suggests that this may not always be true. It notes that "Direct involvement through a trade association generally tends to display a high degree of free riding by SMEs (small and medium enterprises). Although this might not significantly affect the environmental performance of the agreement, it is of concern to its stability—i.e., the actions of SMEs in free riding might jeopardise the whole agreement" (EEA 1997, p. 47). Thus, an important policy question is whether this free-rider incentive, in fact, undermines the viability of a voluntary approach.

To date, the economic literature on voluntary approaches has focused primarily on single-firm models that do not allow for free-riding (e.g., Stranlund 1995; Wu and Babcock 1995, 1996; Cavaliere 1998; Segerson and Miceli 1998, 1999).[4] Two papers that examine the free-riding problem are Maxwell, Lyon, and Hackett (2000) and Millock and Salanié (2000). However, in both of these papers the free-rider problem takes the form of "shirking" by all firms, that is, all firms under-invest in pollution abatement. Neither paper considers equilibria in which a sub-group of firms take voluntary actions, while the remaining firms free-ride. Brau, Carraro, and Golfetto (2000) develop a model in which a sub-group of firms can participate. However, in their model the assumed benefits from participation imply that unless some firms are excluded from participation, under a successful VA no free-riding will occur (i.e., all firms will participate). Thus, their model does not explain the existence of open-membership VAs with less than full participation. The model developed in this paper differs from these previous studies in that it provides an explanation for the existence of free-riding by a subset of firms in equilibrium.

In this paper, we develop a multiple-firm model of voluntary adoption of environmental protection measures in which an entire industry is faced with industry-wide imposition of a costly government policy, namely, an emissions tax. The policy scenario is as follows. A regulator seeks to achieve an exogenous reduction in industry-wide emissions. He sets a target emissions cap for the industry as a whole. He then provides the industry with an opportunity to meet the target voluntarily, with the explicit recognition that if the voluntary approach fails to meet the target, an emissions tax will be imposed on the industry, with the magnitude of the tax set at a level sufficient to ensure that the target

[3] For discussions of the use of regulatory threats to induce voluntary participation, see Goodin (1986), Lévêque and Nadaï (1995), Segerson and Miceli (1998, 1999), and Maxwell, Lyon, and Hackett. (2000).

[4] For surveys of the literature on voluntary approaches, see Alberini and Segerson (2002), Khanna (2001), and Segerson and Li (1999).

will be met under the tax.[5] Because all firms benefit if the target is met but only those firms that reduce their emissions bear costs, firms face a free-rider incentive, that is, an incentive not to participate and reduce emissions voluntarily. We ask whether it is possible to have a successful voluntary approach despite this free-rider incentive.

Because participation in the voluntary program is voluntary and VAs are not legally binding (Stewart 1993; Gaines and Mfodwo 1996), in modeling the voluntary approach we assume that it must be in the interest of all firms to adhere to their participation decisions despite the lack of any legal obligation to do so. To formalize this notion, we adopt the concept of a self-enforcing equilibrium that has been applied to the study of stable cartels and international environmental agreements (IEAs) (d'Aspremont et al. 1983; d'Aspremont and Gabszewicz 1986; Donsimoni, Economides, and Polemarchakis 1986; Carraro and Siniscalco 1993; Barrett 1994). A key contribution of this paper is the application of this concept to the case of industry-wide voluntary agreements and the resulting implications for the effectiveness and efficiency of this approach. Industry-wide VAs differ from IEAs in at least one crucial aspect, namely, the ability to threaten implementation of a regulation or tax if the target is not met voluntarily. This threat plays a key role in our analysis.

Using the concept of a self-enforcing equilibrium, the model predicts that in equilibrium only a subset of firms will participate in an industry-based voluntary program, a result that is consistent with the observations noted above. Nonetheless, the VA is successful in meeting the target, despite the existence (in equilibrium) of free-riders. Thus, the free-rider incentive does not undermine the viability of using a voluntary approach in this context. However, the free-riding that results generates an efficiency loss. This loss does not take the usual form of under-provision of the public good. Rather, the voluntary approach yields an inefficient allocation of total pollution abatement across firms.[6] Thus, although firms benefit from a cost savings under the voluntary approach, total abatement costs are higher than under imposition of the tax.

The paper is organized as follows. Section 2 presents a simple illustrative example of the participation problem and the implications of free-rider incentives. The remainder of the paper then formalizes the results from the example. In Section 3, we provide an overview of the basic model and the equilibrium under the tax policy. Section 4 defines and characterizes the equilibrium under the voluntary approach using the concept of a self-enforcing equilibrium. In Section 5, we identify the efficiency loss from use of the VA and compare the private returns under the two policies. Section 6 summarizes the main conclusions.

II. A SIMPLE ILLUSTRATIVE EXAMPLE

We begin with a simple illustrative example to motivate our analysis. Consider an industry with only two (identical) firms. Let profits of firm i be given by $\pi(e_i) = 20e_i - e_i^2$, where e_i is the emissions level of firm i. In the absence of any government policy, each firm chooses the profit-maximizing level of e_i, which is 10,

[5] The policy approach examined here is similar to the provision point mechanism under which a public good is provided if and only if voluntary contributions are sufficient to cover the cost of providing the good (see, e.g., Lipman and Bagnoli 1989; Bagnoli and McKee 1991; Marks and Croson 1999; Rondeau, Schulze, and Poe 1999). We are indebted to Bill Schulze for noting this similarity. It is also similar to the equilibrium with a minimal contributing set (see, e.g., van de Kragt, Orbell, and Dawes 1983; Rapoport 1985). We are indebted to an anonymous referee for this analogy.

[6] Note that, in a context where individuals contribute to provision of a public good out of their income, free-riding on the part of some individuals would not generate an efficiency loss provided total contributions are sufficient to ensure that the good is provided (assuming provision is efficient). However, in our context, since the public good is actually produced rather than simply financed by individual firms, free-riding behavior causes an efficiency loss since it implies that the allocation of production across firms is not efficient. See further discussion below.

		Firm 2 Choices: Participate (P)	Firm 2 Choices: Do Not Participate (NP)
Firm 1 Choices	Participate (P)	75, 75	0, 100
	Do Not Participate (NP)	100, 0	25, 25

FIGURE 1
Payoff Matrix with a Target of 10 Units

implying total emissions of 20 units. Suppose now that the regulator wants to reduce total emissions to 10 units. One possibility is to impose an emissions tax of $10/unit on each firm. This would induce each firm to reduce emissions to five units, yielding before-tax profits of $75 and after-tax profits of $25 per firm. Alternatively, the regulator could offer the firms a chance to meet the aggregate or collective target voluntarily, with an understanding that if the target is not met voluntarily, the emissions tax will be imposed. Suppose that participation implies a commitment to ensure that the target is met voluntarily. If both firms agree to participate in this voluntary approach, they agree to share the required reduction equally, with each reducing emissions to five units. However, if one agrees to participate and the other does not, then the non-participant will continue to emit 10 units, implying that the participant would have to reduce emissions to 0 units in order to ensure that the collective target is met. The resulting payoff matrix is depicted in Figure 1.

The concept of a self-enforcing equilibrium requires that (1) each participating firm (i.e., each member of the coalition) earn a profit level that is at least as high as it would have earned if no firms participate (profitability); and (2) neither firm be able to benefit by unilaterally changing its participation decision (i.e., joining or leaving the coalition), given the need for participation to remain profitable (stability).[7] For the above example, full participation (P,P) is the only self-enforcing equilibrium. Clearly, (1) is met at this equilibrium. To see that (2) is met as well, note that if one firm (say, Firm 1) "defects," the remaining coalition (of one) will dissolve because it is no longer profitable, making Firm 1 worse off than if it were to stay in the coalition (i.e., continue to participate). Recognizing this, Firm 1 will not defect and the full-participation equilibrium will be self-enforcing.

Note, however, that (P,P) is not a Nash equilibrium. In this example, it is easily shown that the only Nash equilibrium is (NP,NP). Although the two equilibrium concepts yield identical equilibria in some cases (see example below), they differ in an important respect, namely, that the self-enforcing equilibrium requires that the coalition be profitable while the concept of a Nash equilibrium does not have a comparable requirement for individuals. Interestingly, while a pure strategy Nash equilibrium in participation does not necessarily exist, we show below that in our model a self-enforcing equilibrium (in pure

[7] A more formal definition of a self-enforcing equilibrium is given below.

		Firm 2 Choices	
		Participate (P)	Do Not Participate (NP)
Firm 1 Choices	Participate (P)	96, 96	84, 100
	Do Not Participate (NP)	100, 84	64, 64

FIGURE 2
PAYOFF MATRIX WITH A TARGET OF 16 UNITS

strategies) under which the target is met voluntarily always exists.

While the above example illustrates a case where full participation is self-enforcing, it is also possible for partial participation to be self-enforcing. Consider the case where the regulator wants to reduce total emissions to 16 units, either voluntarily or through imposition of a $4/unit emissions tax. The payoff matrix is given in Figure 2.

This payoff matrix yields two self-enforcing equilibria, (P,NP) and (NP,P), both of which imply partial participation. Note that in this example, full participation (P,P) is not a self-enforcing equilibrium.[8] If both firms initially joined the coalition, either firm would have an incentive to defect, knowing that the remaining firm would find it more profitable to meet the target on its own than to face the tax. Given this, (P,P) would not be stable.

Several characteristics of the partial participation equilibria should be noted. First, under either equilibria the collective target is met voluntarily. However, both involve "free-riding" in the sense that the target is met entirely through the abatement efforts of one firm. It is not possible to predict which equilibrium will emerge, that is, which firm will participate and which will not.[9]

Second, as expected, the profit level of the non-participant (the free-rider) is higher than the profit level of the participant. Thus, given a choice, a firm would clearly prefer to be in the equilibrium in which it is the non-participant, rather than the equilibrium in which it is the participant. Nonetheless, in the equilibrium in which it is the participant, participation is still the best response to the strategy of the other firm. Thus, given that the other firm chooses not to participate, the participant is still better off participating than not participating and effectively causing the coalition to dissolve. The reason, of course, is that the tax savings realized by avoiding the tax through participation exceeds the additional abatement cost incurred by reducing emissions from 8 to 6.

[8] Both Maxwell, Lyon, and Hackett (2000) and Millock and Salanié (2000) consider only full participation equilibria.

[9] It is interesting to note that introducing heterogeneity does not necessarily allow us to predict which firm will participate and which will not. As a simple example to illustrate this point, consider a case where the profit functions of the two firms are given by $\pi_1(e_1) = 20e_1 - e_1^2$ and $\pi_2(e_2) = 24e_2 - e_2^2$ and the regulator seeks to reduce emissions to 18 units. In this case, Firm 1 has a lower marginal cost of abatement than Firm 2. Yet, both (P,NP) and (NP,P) are self-enforcing equilibria. At one equilibrium, only the low cost firm participates while at the other equilibrium only the high cost firm participates.

Finally, note that each firm's payoff is higher when the target is met voluntarily than when it is not, implying that both the participant and the non-participant strictly prefer to meet the target voluntarily. However, total before-tax profits are lower ($184 in equilibrium vs. $192 if the tax is imposed), implying that meeting the target voluntarily results in a welfare loss. The explanation is that, because of free-riding, the required emission reduction is not allocated efficiently across the two firms when the target is met voluntarily, while it is allocated efficiently when the tax is imposed. The outcome that involves no free-riding and maximizes both before- and after-tax aggregate profit, namely (P,P), is not a self-enforcing equilibrium.

In the above examples, the self-enforcing equilibria implied that the target would be met voluntarily. It is also possible to construct examples where (NP,NP) is also a self-enforcing equilibrium. For example, if the collective target was set at 12 units instead of 16, three self-enforcing equilibria exist: (P,NP), (NP,P), and (NP,NP). The observations above continue to hold, except that in this case the participant is indifferent between the equilibrium under which the target is met voluntarily and the equilibrium under which the tax is imposed.

The above examples provide some intuition for the results that we derive more generally below.

III. AN OVERVIEW OF THE MODEL

We consider a model with N identical firms. Each firm produces an output level y_i and an emission level e_i. The firm's production costs are given by a continuous function $C(y_i,e_i)$, where $C_y > 0$, $C \leq 0$, $C_{yy} \geq 0$, $C_{ee} \geq 0$, and $C_{ye} \leq 0$. The cost function is assumed to be the same under both the emission tax policy and the VA, that is, no cost advantage exists per se from reducing emissions voluntarily. This is in contrast to other models that assume that any given level of emissions reduction can be achieved at a lower cost under the VA than under the alternative policy (typically, a regulation), because the VA gives the firm greater flexibility in choosing its pollution control measures.[10] It is assumed that firms do not benefit directly from reductions in emissions.[11] Thus, absent any government policy, firms have no private incentive for pollution abatement.[12]

As noted above, the regulator seeks to meet an exogenously determined aggregate emissions cap E, where $0 < E < Ne_0$ and e_0 is the equilibrium level of emissions for each firm prior to any government policy.[13] If in the aggregate the firms meet the emissions cap voluntarily, the regulator will not impose a tax on the industry. However, if the firms fail to meet the cap collectively, the regulator will impose a uniform emission tax t on the entire industry, with the magnitude of the tax set at the level necessary to ensure that the emissions cap E is met.[14]

Because the incentive to participate in the voluntary initiative depends on the payoffs

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[10] See, e.g., Segerson and Miceli (1998) and Segerson and Dawson (2001).

[11] Because our interest is in the design of environmental policy, we focus on regulatory threats as a motivation for participation in a VA and ignore any reputational gains or any gains that might result from appealing to "green consumers." As noted in the Introduction, these gains provide a potential motivation for "green production" that is independent of any government policy (see, e.g., Arora and Gangopadhyay 1995).

[12] This is in contrast to the literature on international environmental agreements (e.g., Carraro and Siniscalco 1993; Barrett 1994; Becker and Easter 1999), which is generally concerned with global pollutants. In these models, all countries benefit directly from both their own abatement and the abatement of other countries.

[13] Note that if $E = 0$, i.e., if the government seeks to ban emissions entirely, then even under a tax policy that meets the target the firms will make no tax payment (since emissions are zero). In this case, firms do not benefit from meeting the target voluntarily rather than having the tax imposed.

[14] We do not consider a case where the regulator would impose a tax only on those firms that did not participate in the voluntary programs. Some voluntary programs are of this type, i.e., they allow individual firms to avoid a (higher) tax by participation in a voluntary program (Chidiak 1999; Millock 1999). Here we are interested in a case where the regulator treats the industry as a single entity. If imposed, the tax would apply to all firms. If it is not imposed, all firms (including those who do not participate in the voluntary program) avoid the tax. Note that such an approach requires monitoring of only aggregate emissions (perhaps through ambient monitoring) rather than the monitoring of each individual source.

that firms can expect to realize if the tax is imposed, we consider first the equilibrium under a tax. We view this as a three-stage game. In Stage 1, the government agency or regulator sets the emissions tax rate. In Stage 2, each firm chooses its emissions level, taking the emissions levels of all other firms as given. In Stage 3, the firms engage in Cournot competition in the output market, facing an aggregate demand curve of $P(Y)$,[15] where $Y = \sum_1^N y_i$.

In a symmetric Nash equilibrium, Stage 3 Cournot competition yields profit-maximizing output levels $y_i^t = y^t(e)$ that are the same for all firms and depend on the (common) emissions level chosen in Stage 2.[16] Substituting these into each firm's profit function gives before-tax profits as a function of e, that is, $\pi(e) \equiv P(Y^t(e))y^t(e) - C(y^t(e),e)$, where $Y^t(e) = Ny^t(e)$. In Stage 2, each firm chooses its emissions level to maximize after-tax profits $\pi(e) - te$, given the emissions levels of all other firms. This yields an optimal emissions level $e^*(t)$, which depends on the tax rate t.[17] In Stage 1, the regulator sets the tax rate to ensure that the target will be met. The resulting tax rate t^* is implicitly defined by $Ne^*(t^*) = E$. Note that t^* is homogeneous of degree zero in (N,E). Thus, the emissions tax depends only on the stringency of the emissions cap (E/N). If faced with this tax, each firm will earn an after-tax profit level of $\pi_t^* \equiv \pi(e^*(t^*)) - t^*e^*(t^*))$.

IV. EQUILIBRIUM UNDER THE VA

We turn next to the equilibrium under the voluntary approach. Again, we view the problem as a three-stage game. In Stage 1, each firm decides whether or not to join the group of firms that participate in the voluntary approach, where participation entails a commitment to share equally with all other participants the emission reductions that are necessary to ensure that the collective target is met. Note that, instead of treating the participation decision separately, we could have simply modeled the firms' emission choices as a Nash equilibrium. This is the approach taken in the economic literature on minimum contributing sets and provision points (e.g., Van de Kragt, Orbell, and Dawes 1983; Rapoport 1985; Bagnoli and Lipman 1989; Bagnoli and McKee 1991). Following the literature on international environmental agreements (e.g., Carraro and Siniscalco 1993; Barrett 1994), we chose to model participation as a separate decision using the concept of a self-enforcing equilibrium.[18]

The justification for modeling the participation decision separately is both empirical and theoretical. First, on the empirical side,

[15] Although we do not specify a form for $P(Y)$, we assume throughout that its curvature, coupled with the curvature of the cost function given above, ensure that all second-order conditions are satisfied.

[16] These are derived from the standard first order conditions, i.e., $P'(Y)y_i + P(Y) - C_y(y_i,e_i) = 0$ for all i, which are sufficient given the assumption in footnote 15. Note that if the firm's cost function is strongly separable, i.e., if $C_{ye} = 0$, then the optimal output choice will not depend on the emissions level.

[17] Using the envelope theorem, the first order conditions defining the optimal emissions levels become $P'(Y^t(e))y_i^t(e)\left\{\Sigma_{j\neq i}\partial y_j^t \big/ \partial e_i\right\} - C_e\left(y_i^t(e),e_i\right) - t = 0$ for all i.

[18] The difference between the two approaches can be illustrated using the example in Section 2. Note that in this example, although (P,P) is not a Nash equilibrium in participation, (e_1,e_2)=(5,5) is a Nash equilibrium in the emission choices. The reason is that, under the self-enforcing equilibrium, if one firm chooses to "defect" and hence not participate, it is assumed that the other participating firm will reduce its emissions to ensure the target is still met, provided it is profitable for it to do so. In contrast, under the Nash equilibrium in emission choices, when one firm considers reducing its emissions below 5, it assumes that the other firm will continue to emit 5 units. Note that the self-enforcing equilibria that we identify would also be equilibria if we modeled emissions decisions as a Nash equilibrium. However, some of the equilibria under this latter approach would not be self-enforcing. Hence, our approach uses what is in a way a narrower class of equilibria (i.e., imposes a stronger condition), than the Nash equilibrium in emissions and one which we feel (for reasons given below) is more empirically relevant in our context. Had we modeled Nash equilibria in emission decisions, the only result that would change is that we would not be able to rule out an equilibrium under which all firms participate and the first-best is achieved under the VA. However, since we are primarily interested in whether VAs that *do not* involve full participation can still be effective, our major conclusion (namely, that a VA can be successful despite the existence of free-riding) would not be changed. For a related application to nonpoint pollution using the Nash equilibrium approach, see Segerson and Wu (2006).

many actual VAs involve an explicit "sign-up" or "participation" action by firms. For this reason, much of the empirical literature on VAs has focused on participation as a separate decision of firms (e.g., Arora and Cason 1995, 1996; Khanna and Damon 1999; Videras and Alberini 2000; Delmas and Keller 2005; Alberini 2007). Given this, we feel that our approach is more empirically relevant than an approach that simply models the emissions decision and treats any non-zero reduction as "participation." In addition, modeling participation as a separate decision has ample precedent in the theoretical literature. For example, Dixit and Olson (2000) use a two-stage approach to argue that even if Coasian bargaining leads to efficiency among those parties who come to the bargaining table, the voluntary decision about whether to come to the bargaining table (i.e., whether to participate) results in free-riding.[19] Similarly, in the context of environmental protection, the seminal papers by Carraro and Siniscalco (1993) and Barrett (1994) both use this approach to predict the likely outcomes under international environmental agreements. Our model is effectively an application of their approach to voluntary agreements among firms rather than among countries. Thus, for both empirical and theoretical reasons, we believe that modeling the participation decision separately in the first stage is reasonable and appropriate in our context.

The outcome of the first stage participation decisions determines the next stage. If no firms choose to participate in Stage 1, the VA fails and the firms play the tax game described in the previous section.[20] If some firms choose to participate, the game proceeds to Stage 2. In Stage 2, each non-participant chooses its emissions level to maximize profits, given the emissions levels of all other non-participating firms and the commitment of participating firms. In Stage 3, all firms engage in Cournot competition in the output market. We model the Stage 2 and Stage 3 decisions as Nash equilibria.[21] For simplicity, we consider only symmetric equilibria in Stages 2 and 3, that is, equilibria in which all participating firms choose the same emissions and output levels[22] and all non-participating firms do as well. In contrast, as noted above, because Stage 1 decisions involve commitment to join a group or coalition, we model the Stage 1 equilibrium using the concept of a self-enforcing equilibrium.

Let N_p denote the number of firms that choose to participate in Stage 1, and let $N_n = N - N_p$ be the number of non-participating firms. We solve the game through backward induction and hence consider the Stage 3 equilibrium first. Let e_p denote the (common) emissions level of a participating firm, and let e_n denote the corresponding level for a non-participating firm. In Stage 3, both types of firms choose their output levels to maximize their own profits, given these emissions levels. More specifically, participating firms choose the output level y_p that maximizes[23]

$$P(y_p + (N_p - 1)\bar{y}_p + (N - N_p)\bar{y}_n)y_p - C(y_p, e_p), \quad [1]$$

while non-participating firms choose the output level y_n that maximizes

$$P(N_p\bar{y}_p + (N - N_p - 1)\bar{y}_n + y_n)y_n - C(y_n, e_n). \quad [2]$$

[19] Dixit and Olson (2000) use the concept of subgame perfection rather than the concept of a self-enforcing equilibrium to model the participation decision since participation does not imply a collective commitment.

[20] For simplicity, we assume that the failure of the VA is detected and the tax is imposed instantaneously. In a two-period model in which detection occurs in the first period and the tax is imposed in the second period, the total payoffs would depend on the discount rate. See Millock and Salanié (2000) and Segerson and Wu (2006) for multi-period models of VAs.

[21] Since the group of participants collectively agrees to ensure that the target is met, it might seem more appropriate to assume that they cooperate in their choice of output levels as well. However, in many countries such cooperation in the output market would be illegal under anti-trust laws. For this reason, we assume that all firms, including all participating firms, act non-cooperatively when choosing output.

[22] With identical firms, this is the most efficient allocation of emissions across the set of participating firms. It is also the allocation that would result from joint profit maximization or Nash bargaining by participating firms.

[23] Bars over variables indicate that the firm takes these variables as given.

The corresponding Nash equilibrium yields output levels $y_p^*(e_p, e_n, N_p)$ and $y_n^*(e_p, e_n, N_p)$. The corresponding profit levels are

$$P(Y^*(e_p, e_n, N_p))y_p^*(e_p, e_n, N_p) - C\left(y_p^*(e_p, e_n, N_p), e_p\right), \quad [3]$$

and

$$P(Y^*(e_p, e_n, N_p))y_n^*(e_p, e_n, N_p) - C(y_n^*(e_p, e_n, N_p), e_n), \quad [4]$$

respectively, where

$$Y^*(e_p, e_n, N_p) = N_p y_p^*(e_p, e_n, N_p) + (N - N_p)y_n^*(e_p, e_n, N_p).$$

Given the optimal output choices and resulting profits levels from Stage 3, we now consider the equilibrium in Stage 2. A Stage 2 equilibrium is defined by two conditions. The first is that each non-participating firm chooses its emissions level to maximize its profits in [4], given the emissions levels of all other firms.[24] The second condition requires that the emissions level for each participating firm be the level that ensures that the target is met, given the emissions levels of the non-participating firms, that is,

$$e_p = \{E - (N - N_p)e_n\}/N_p. \quad [5]$$

These two conditions combined determine the equilibrium emissions levels $e_p^*(N_p)$ and $e_n^*(N_p)$ as functions of the number of participating firms. Note that, if both the emissions cap and the number of participating firms are sufficiently low and the unconstrained level of emissions is sufficiently high, it may not be possible for an arbitrary number of participating firms to ensure that the aggregate target is met. For example, if $N = 10$ and $e_0 = 10$, an aggregate emissions cap of 50 could not be met at any participation rate less than or equal to 50%, since e_p in [5] would be less than zero. Thus, for an arbitrary participation rate, a voluntary approach may not even be feasible. However, we show below that an equilibrium with a successful voluntary approach always exists, and it must, by definition, be feasible (i.e., have $e_p \geq 0$).

Substituting the emission levels $e_p^*(N_p)$ and $e_n^*(N_p)$ into [3] and [4] gives the maximized level of profits for participants and non-participants, $\pi_p^*(N_p)$ and $\pi_n^*(N_p)$, as functions of the number of participating firms. Note that an increase in N_p can affect the profits of both participating and non-participating firms in two ways: (1) through the impact on emissions (a direct effect), and (2) through the impact on output choices (an indirect effect). To see the direct effect, first note that if the cost function is strongly separable, that is, if $C_{ye} = 0$, then the Stage 3 equilibrium, that is, the optimal output choice, is independent of the emissions levels. This implies that both participating and non-participating firms will choose the same output levels, which in turn implies that both those output levels and the corresponding price will be independent of the number of participating firms. Thus, the effect of N_p on profits is just the direct effect that occurs through the choice of emissions level. For non-participating firms, the emissions level that would be chosen under separability is determined by the first-order condition

$$-C_e = 0, \quad [6]$$

which is independent of N_p. Thus, under separability, $\partial\pi_n^*/\partial N_p = 0$, that is, the direct effect is zero. For participating firms, the level of emissions is determined by [5]. This implies that

$$\partial\pi_p^*\Big/\partial N_p = C_e(E - Ne_n)\Big/N_p^2 > 0. \quad [7]$$

Thus, as expected, an increase in the number of participating firms directly increases the profits of each participating

[24] The corresponding first-order condition is similar to the condition given in footnote 17 with the tax set equal to zero.

firm, since the emissions reduction that each participant must undertake to ensure the target is met is reduced when the number of participants increases.

When the cost function is not strongly separable, a second, indirect effect exists as well. In this case, the firms' optimal output choices depend on emissions levels since emissions levels affect marginal production costs. Hence, output choices will be different for participating and non-participating firms, implying that the total output (and hence price) in the market will depend on the number of participating firms. This price effect then further affects equilibrium output levels and thus profits. While these indirect effects through the output market can exist, the existing empirical evidence suggests that even for heavily polluting industries emission abatement costs constitute a relatively small share of production costs (see, e.g., Jaffe et al. 1995). For this reason, we assume throughout the remainder of the paper that these effects are "small," and hence that the total effects of a change in the number of participating firms are dominated by the direct effects described above. Thus, in what follows we assume that an increase in the number of participating firms increases profits for participating firms but has no significant effect on the profits of non-participants. Note that this implies that $\pi_n^*(N_p) \equiv \pi_n^* > \pi_p^*(N_p)$ for all $N_p < N$. This simply says that when the target is met at any participation rate less than full participation, non-participants earn a higher profit than participants.

We are now in a position to identify the Stage 1 equilibria that are self-enforcing, that is, both profitable and stable (both externally and internally) in the sense defined in the literature on international environmental agreements and stable cartels (d'Aspremont et al. 1983; d'Aspremont and Gabszewicz 1986; Donsimoni, Economides, and Polemarchakis 1986; Carraro and Siniscalco 1993; Barrett 1994). The need for self-enforcement stems from the fact that participation in the voluntary approach is not binding. Hence, in equilibrium the participation decisions of all firms and the resulting number of participating firms should be such that continued participation in the group is in the self-interest of participating firms, and no non-participants want to join. This requires that the equilibrium be both profitable and internally and externally stable.

An equilibrium (N_p) is *profitable* if $\pi_p^*(N_p) \geq \pi_t^*$, that is, if at this equilibrium the participating firms are at least as well off under the voluntary program as they would have been without the program (and hence with the tax).[25] Furthermore, an equilibrium is both internally and externally stable if (1) no participating firm has an incentive to defect unilaterally, that is, to become a non-participating firm; and (2) no non-participating firm has an incentive to join unilaterally, that is, to become a participating firm.[26]

To identify equilibria that are stable, we must define more explicitly the payoffs from participation (and hence from accession and defection) at various levels of participation. To do this, we first define N_p^* to be the minimum number of participating firms necessary to make the voluntary approach profitable for the participating firms.[27] Thus, if $\pi_p^*(1) < \pi_t^*$, then N_p^* is the

[25] If joining the voluntary program entails a fixed cost F, then the condition for profitability would become $\pi_p^*(N_p) - F \geq \pi_t^*$. This would increase the minimum participation level defined below, but, with the appropriate changes in the subsequent definitions, would not otherwise change the qualitative results.

[26] As in the stable cartel literature, we do not consider the possibility of transfers between participating and non-participating firms. Some IEA studies allow this kind of transfer (Carraro and Siniscalco 1993; Botteon and Carraro 1997). However, transfers seem unlikely in our context.

[27] N_p^* is similar to the notion of the "minimal contributing set (MCS)", which has been advocated as a solution to the public goods problem (e.g., van de Kragt, Orbell, and Dawes 1983; Rapoport 1985). However, the MCS mechanism is typically defined as the minimum number of individuals who must contribute a given amount to reach a pre-specified target that ensures provision of the public good. Since the target and the size of an individual's possible contribution are both fixed, the MCS is exogenously specified. In contrast, in our context an individual firm's "contribution" can vary (allowing for the possibility that it will exceed the first-best level), which implies that the number of firms that must contribute to ensure that the target is met is endogenously determined.

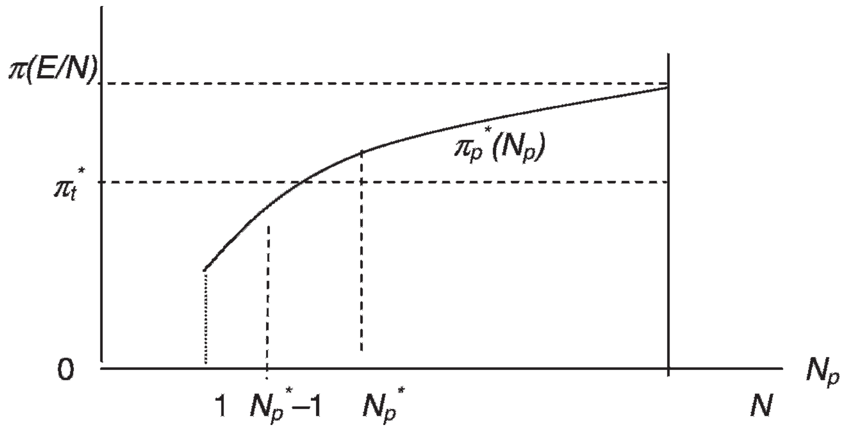

FIGURE 3
MINIMUM PARTICIPATION LEVEL WHEN $\pi_p^*(1) < \pi_t^*$

level of N_p such that

$$\pi_p^*\left(N_p^*\right) \geq \pi_t^*, \text{ but } \pi_p^*\left(N_p^* - 1\right) < \pi_t^*. \qquad [8]$$

This is illustrated graphically in Figure 3. Alternatively, if $\pi_p^*(1) \geq \pi_t^*$, that is, if it is profitable for one firm to meet the target on its own, then $N_p^* = 1$. Clearly, any value of $N_p < N_p^*$ implies that the coalition is not profitable. In addition, given $\partial\pi_p^*\big/\partial N_p^* > 0$, if a coalition is profitable at N_p^*, it is profitable for any higher level of participation. Thus, the only possible self-enforcing equilibria are equilibria with $N_p \geq N_p^*$.

Because of the importance of N_p^* in identifying and characterizing the self-enforcing equilibria, before proceeding we establish the existence of a minimum profitable participation level.

PROPOSITION 1. *A unique minimum profitable participation level N_p^* always exists, where* $1 \leq N_p^* \leq N$.

PROOF. If $\pi_p^*(1) \geq \pi_t^*$, then by definition N_p^* exists and is equal to one. Suppose instead that $\pi_p^*(1) < \pi_t^*$. In addition, note that $\pi_p^*(N) = \pi(E/N) > \pi_t^*$. This, coupled with the continuity and monotonicity of $\pi_p^*(N_p)$, ensures the existence of a unique value of $1 < n \leq N$, at which $\pi_p^*(n) = \pi_t^*$. N_p^* is then simply the largest integer greater than or equal to n. QED

To determine which of the profitable equilibria are stable, we note that a level of participation that is not profitable will lead to a dissolution of the coalition and hence the imposition of the tax. Conversely, a level of participation that is profitable will yield the payoffs described above, which were conditional on the collective target being met voluntarily, that is, on the coalition being profitable. Thus, the unconditional payoffs for participants and nonparticipants are given by

$$\pi_p(N_p) = \begin{cases} \pi_t^* & \text{if } N_p < N_p^* \\ \pi_p^*(N_p) & \text{if } N_p \geq N_p^* \end{cases}$$

and

$$\pi_n(N_p) = \begin{cases} \pi_t^* & \text{if } N_p < N_p^* \\ \pi_n^* & \text{if } N_p \geq N_p^*. \end{cases}$$

Note that at $N_p = N$, $\pi_p(N_p)$ is equal to the profit level that would be realized if all firms participated and hence shared equally in the allowable emissions, $\pi(E/N)$. This profit level exceeds π_t^* by the amount of the tax payment, t^*E/N.

The two profit functions defined above are depicted in Figure 4. They can now be used to define external and internal stability of an equilibrium.

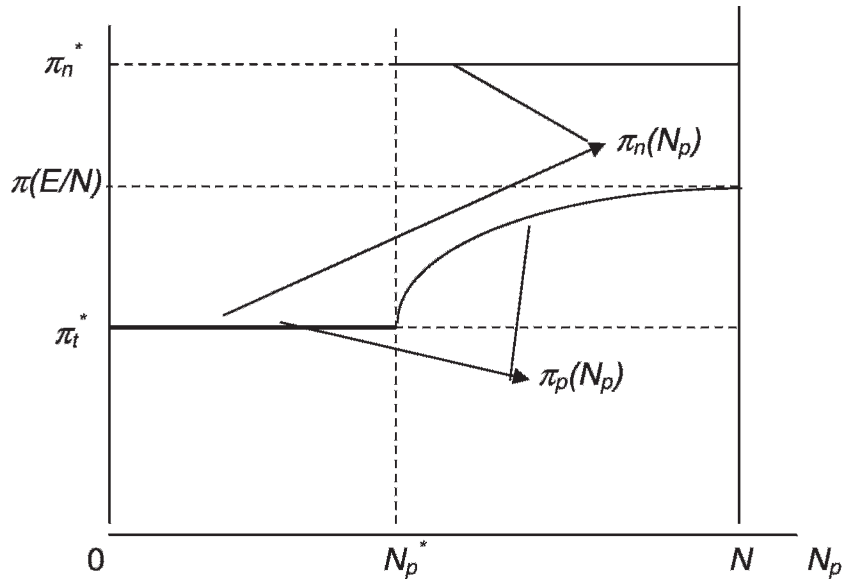

FIGURE 4
Unconditional Profit Function of Participating and Non-Participating Firms

Definition. *An equilibrium with N_p firms participating is internally and externally stable if, and only if,*

(1) $\pi_p(N_p) \geq \pi_n(N_p - 1)$ (*no firm has an incentive to defect*), *and*
(2) $\pi_n(N_p) \geq \pi_p\,(N_p + 1)$ (*no firm has an incentive to accede*).

Using the definition of stability and the above profit functions, we can establish the following.

Proposition 2. *A coalition of N_p participating firms is a self-enforcing equilibrium under which the target is met voluntarily if and only if $N_p = N_p^*$.*

Proof. The "if" part of the proposition is easily verified using the profit functions above. For the "only if" part, we need to consider only values of N_p for which $N_p > N_p^*$ (since any outcome with $N_p < N_p^*$ is by definition not profitable and hence cannot be a self-enforcing equilibrium). However, for any integer $N_p > N_p^*$, $N_p - 1 \geq N_p^*$. Thus, $\pi_n\left(N_p - 1\right) = \pi_n^* > \pi_p\left(N_p\right) = \pi_p^*\left(N_p\right)$, which violates (1). Thus, any equilibrium with $N_p > N_p^*$ cannot be self-enforcing. QED

Proposition 2 implies that the only self-enforcing equilibrium is the equilibrium with the minimum amount of profitable participation. Thus, as long as $N_p^* < N$, a full participation equilibrium will not be self-enforcing. Some amount of free-riding is expected to occur under a successful voluntary approach because of the tax savings generated by the voluntary program.[28] Note that because of the cost savings that result from avoiding an emissions tax, participating firms are willing to reduce their emissions to a level below what they would have chosen under the tax (E/N).

At the self-enforcing equilibrium the profit level is higher for non-participating firms than for participating firms. Thus, if a

[28] A full participation equilibrium would only be self-enforcing if the tax savings from meeting the target voluntarily were sufficiently small that free-riding by even one firm would make the voluntary approach unprofitable. This is more likely to occur when the number of firms in the industry is small.

participating firm could exchange places with a non-participating firm, that is, become a non-participant without affecting the number of participating firms, it would always have an incentive to do so. However, the conditions for stability ensure that in a self-enforcing equilibrium, a participating firm has no incentive to defect *unilaterally*, despite the fact that it realizes lower profits than the non-participating firms. The reason, of course, is that at the self-enforcing equilibrium the coalition would fall apart if one firm unilaterally defected (since it would no longer be profitable), which would trigger imposition of the tax and thereby yield a profit level for the would-be defector that was no higher than it would have realized if it had continued to participate in the voluntary approach.

We turn next to a key result that establishes the viability of the voluntary approach.

Proposition 3. *A self-enforcing equilibrium under which the target is met voluntarily always exists.*

Proof. This follows directly from Propositions 1 and 2. QED

The intuition behind Proposition 3 is as follows. It is clear that a coalition with full participation is always profitable since each firm incurs the same abatement cost as it would have incurred under the tax but avoids the tax payment. If defection by a single firm would yield a coalition size that is not profitable, then the full coalition is self-enforcing. If a coalition of size $N - 1$ is still profitable, then the full coalition is not stable, but the coalition of size $N - 1$ is a possible self-enforcing equilibrium (if it is stable). By iteratively moving backward starting from the full coalition, we can identify the coalition size where any further defections would yield a remaining coalition that is not profitable. This coalition is then stable and profitable, and hence self-enforcing. If the coalition of one (i.e., $N_p = 1$) is not profitable, then this iterative process will stop at a coalition size greater than, or equal to two, under which the target would be met voluntarily. Conversely, if the coalition of one is profitable, this iterative process will stop at the coalition of one, since under this condition this coalition is also stable (i.e., the single participant cannot do better by defecting). Thus, in either case, the iterative process will stop at a coalition of strictly positive size, implying the existence of a self-enforcing equilibrium under which the target is met voluntarily. Note that this implies that, even if a voluntary program is not feasible for a low N_p,[29] a value of $N_p \geq 1$ always exists at which the target can be met voluntarily, and in a manner that is profitable in the sense defined above.

While the minimum participation equilibrium is the only self-enforcing equilibrium under which the target is met, it is also possible to have a self-enforcing equilibrium under which the target is not met.

Proposition 4. $N_p = 0$ *is a self-enforcing equilibrium under which the target is not met voluntarily If and only if* $\pi_p^*(1) \leq \pi_t^*$.[30]

Proof. Since no firms participate, profitability holds trivially. In addition, if $\pi_p^*(1) \leq \pi_t^*$, then at $N_p = 0$, $\pi_n(N_p) = \pi_t^* \geq \pi_p^*(N_p + 1)$, which implies that no firm has an incentive to accede to form a coalition of one. Conversely, if $\pi_p^*(1) > \pi_t^*$, then $\pi_n(N_p) = \pi_t^* < \pi_p^*(N_p + 1)$, which implies that $N_p = 0$ is not stable and hence not self-enforcing. QED

Note, however, that even if the zero participation outcome is self-enforcing, a self-enforcing equilibrium with positive participation (N_p^*) also exists (by Proposition 3). In addition, each firm in the industry is at least as well off and some are strictly better off at the equilibrium under which the target is met voluntarily than at the equilibrium under which it is not. In this sense, the equilibrium under which the target is met voluntarily Pareto dominates. Thus, even when multiple self-enforcing equilibria exist, we might expect

[29] This occurs when $N_p < N - (E/e_n)$, so that $e_p < 0$.

[30] Note that the payoffs in Figure 2 satisfy this condition while the payoffs in Figure 1 do not.

firms to choose the equilibrium under which the target is met voluntarily.

V. POLICY COMPARISONS

The results in the previous section imply that, unless $N_p^* = N$, some amount of free-riding will result under a successful voluntary approach, because of the tax savings that can be realized if the emissions cap is met voluntarily. Note, however, that because the cap is met under either the tax policy or the voluntary program, free-riding does not lead to under-provision of the public good (environmental quality). It does, however, affect both the total private and social costs of supplying that level of the public good.

PROPOSITION 5. *Aggregate profit for the industry is higher when the target is met voluntarily than under the emissions tax.*

PROOF. The industry-wide aggregate profits under the tax policy are given by $\Pi_t = N\pi_t^*$.

Aggregate profits when the target is met voluntarily are

$$\Pi_V = \left(N - N_p^*\right)\pi_n^* + N_p^*\pi_p^*\left(N_p^*\right).$$

Thus,

$$\Pi_V - \Pi_t = \left(N - N_p^*\right)\left(\pi_n^* - \pi_t^*\right) + N_p^*\left(\pi_p^*\left(N_p^*\right) - \pi_t^*\right) > 0, \qquad [9]$$

where the inequality follows from $\pi_n^* > \pi_t^*$ and $\pi_p^*\left(N_p^*\right) \geq \pi_t^*$. QED

Thus, as expected, aggregate profits are higher when the target is met voluntarily than when it is met through imposition of the tax, since at a self-enforcing equilibrium all firms are at least as well off under the voluntary program as they are under the tax. Interestingly, however, in equilibrium the aggregate profit gain that results from the use of the voluntary program is not the aggregate tax savings (t^*E). The profit differential for the non-participants exceeds the magnitude of their tax savings (which is t^*E/N per firm). It reflects the gain *both* from not having to pay any tax on emissions and from not having to undertake any abatement under the voluntary approach. In contrast, when $N_p^* < N$, the profit gain to participants is less than the magnitude of their tax savings, since they undertake more abatement under the voluntary program than they would have undertaken under the tax.[31]

Given the result in Proposition 5, we would expect the industry as a whole to prefer the voluntary program, since all firms are individually at least as well off and collectively better off than under the tax. However, as stated below, use of the voluntary approach will actually lead to higher social costs than would have resulted under the tax policy.

PROPOSITION 6. *If $N_p^* < N$, the total social cost of meeting the emissions cap E is higher when the target is met voluntarily than under the tax policy.*

This follows directly from the fact that, when firms are identical and the profit function is strictly concave,[32] the total cost of meeting the cap is minimized when emissions are distributed equally across all firms (Baumol and Oates 1988). This occurs under the tax policy (all firms emit $e_t^*(t^*)$), but not under the voluntary approach (since in equilibrium participants emit less than non-participants). Thus, despite the fact that no firm is any worse off under the voluntary program and each participating firm has full flexibility to meet its own emission level in a cost-minimizing way, using a voluntary program rather than a tax to meet the aggregate emissions cap generates a social cost because of the unequal

[31] When $N_p^* = N$, the profit differential for all firms is simply their tax savings, since all firms undertake the same amount of abatement under the voluntary approach as under the tax.

[32] With a linear profit function, aggregate profits are independent of the allocation of abatement across firms.

(and hence inefficient) distribution of abatement across firms.[33]

The increased social costs associated with the voluntary approach stem from the threatened imposition of an emissions tax, which is costly to firms. If the regulator could credibly threaten imposition of a first-best regulation,[34] under which each firm would realize a profit of $\pi(E/N)$, the results would be different. In this case, the only self-enforcing equilibrium under which the target is met is the full-participation equilibrium. With full participation, the allocation of abatement is efficient across all firms and thus total social costs are the same under the regulation as under the voluntary approach. However, under a first-best regulation the industry does not realize a gain from the voluntary approach.[35] Hence, neither the industry nor the regulator has a reason to want to use the voluntary approach.

VI. SUMMARY AND CONCLUSIONS

Policymakers are increasingly interested in the use of voluntary approaches to environmental protection as an alternative to more traditional regulatory approaches. In many cases, entire industries are faced with possible imposition of costly environmental policies if environmental goals are not met voluntarily. If the threat is industry-wide, a potential free-rider problem exists since, if the environmental goal is met by others, individual firms would benefit from avoidance of the costly policy without incurring the associated cost.

In this paper, we developed a multiple-firm model in which an industry is faced with an aggregate emissions limit and given an opportunity to meet the target voluntarily, with the explicit recognition that failure to do so would result in imposition of an industry-wide emissions tax. Faced with this prospect, we ask whether a voluntary approach can be successful, given the incentive for individual firms to free ride. We show that a self-enforcing equilibrium under which the target is met voluntarily always exists, and occurs at the minimum profitable participation level. Thus, the only self-enforcing equilibrium under which the target is met voluntarily will involve free-riding (unless free-riding by just one firm makes the coalition unprofitable). The zero participation outcome (under which the target is not met voluntarily) can also be a self-enforcing equilibrium. However, it is Pareto dominated by the equilibrium under which the target is met voluntarily. Thus, even though free-riding is a likely outcome in equilibrium (i.e., a self-enforcing equilibrium will not generally involve full participation), the free-rider incentive does not destroy the viability of successfully using an industry-wide voluntary approach.

As expected, free-riding generates an efficiency loss. However, this loss does not take the usual form of under-provision of the public good. Rather, it takes the form of an increase in the cost of providing the targeted level of the public good. An emissions tax ensures that the aggregate

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[33] Proposition 6 identifies a distortion that results when the target is met voluntarily by a subset of firms in the industry. With imperfect competition in the output market, a second distortion exists as well. A full welfare comparison between the two policy approaches requires consideration of not only the different aggregate abatement costs but also the different aggregate output levels under the tax and voluntary approach. Under separability ($C_{ye} = 0$), aggregate output is the same under the two policies. However, without separability the two can be different. If the voluntary approach leads to less output because of higher cost, this would exacerbate the efficiency loss that stems directly from the inefficient allocation of abatement across firms.

[34] By first-best, we mean a regulation that provides the flexibility for each firm to achieve its emission reductions in the least cost way (such as a performance standard) and ensures an efficient allocation across firms. It is well-known, however, that regulation does not provide efficient long-run entry/exit incentives. See, e.g., Baumol and Oates (1988).

[35] In contrast, if the regulator threatens imposition of an inefficient regulation, both society and the industry can benefit from use of the voluntary approach. Segerson and Dawson (2001) show that under the threat of the imposition of a regulation that is not fully efficient (e.g., one that does not allow the firm full flexibility in determining how the standard will be met), the total social cost of meeting an exogenous environmental quality standard will always be lower under the voluntary approach than under the regulation, even though in equilibrium only partial participation will occur.

emissions target is met at least cost. With identical firms, this results when emissions reductions are allocated uniformly across firms. Under the voluntary approach, the allocation of emissions reductions is no longer uniform, since participating firms reduce emissions by more than non-participants. This unequal distribution of abatement across firms results in a higher overall cost of meeting the aggregate emission reduction goal. Thus, despite the fact that firms have full flexibility to meet their emissions reductions in the least cost way, total social costs are higher under the voluntary approach.

Although the voluntary approach results in higher social costs, it generates a gain for both participating and non-participating firms, and hence for the industry as a whole. This gain stems from the avoided tax payments. However, the magnitude of that gain is not given by the amount of the avoided tax payments. Non-participants gain more than their avoided tax payments, while participants gain less. Nonetheless, all firms are at least as well off and some are always strictly better off than under the tax alternative, which suggests that the industry would prefer the voluntary approach.[36]

Would a regulator ever prefer the voluntary approach? Within the context of the model developed here, a welfare-maximizing regulator would never prefer the voluntary approach to the tax, because of the increase in the social cost of meeting the target.[37] However, the model abstracts from a number of potential benefits from using a voluntary approach (such as increased cooperation and reduced political resistance—see, e.g., CEC 1996) as well as potential imperfections in the design of an emissions tax (such as an inability to tax all emissions—see, e.g., Nyborg 2000). Consideration of these potential benefits of the voluntary approach would have to be weighed against the cost generated by free-riding in assessing the overall welfare implications of an industry-wide voluntary approach.

Finally, although our focus has been on industry-based voluntary agreements in a context where the regulator can penalize an entire industry but cannot target individual firms (e.g., non-participants), the general principles we have derived here could have implications for other contexts with a similar structure. For example, in an international context, it may be possible for an international body to impose sanctions that affect the economy as a whole even if it cannot directly sanction individual firms that fail to contribute to a given goal. Our results would suggest that the threat of sanctions might be effective in inducing compliance with the goal, but in a way that is not necessarily cost-effective.

[36] Nyborg (2000) notes that lobbying for the Norwegian voluntary agreements regarding waste packaging was a reaction to a real and credible threat of imposition of a packaging tax.

[37] This assumes that there is no compensating efficiency gain in the output market from a sufficiently large increase in output.

References

Alberini, A. 2007. "Determinants and Effects on Property Values of Participation in Voluntary Cleanup Programs: The Case of Colorado." *Contemporary Economic Policy* 25 (3): 415–32.

Alberini, A., and K. Segerson. 2002. "Assessing Voluntary Programs to Improve Environmental Quality." *Environment and Resource Economics* 22 (1/2): 157–84.

Arora, S., and T. N. Cason. 1995. "An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program." *Journal of Environmental Economics and Management* 28 (3): 271–86.

———. 1996. "Why Do Firms Volunteer to Exceed Environmental Regulation? Understanding Participation in EPA's 33/50 Program." *Land Economics* 72 (Nov.): 413–32.

Arora, S., and S. Gangopadhyay. 1995. "Toward A Theoretical Model of Voluntary Overcompliance." *Journal of Economic Behavior and Organization* 28 (3): 289–309.

Aggeri, F., and A. Hatchuel. 1999. "A Dynamic Model of Environmental Policies." In *Voluntary Approaches in Environmental Policy*, ed. C. Carraro and F. Lévêque, 151–85. Dordrecht: Kluwer Academic Pub.

Bagnoli, M., and B. L. Lipman. 1989. "Provision of Public Goods: Fully Implementing the Core through Private Contributions.'' *Review of Economic Studies* 56 (4): 583–601.

Bagnoli, M., and M. McKee. 1991. ''Voluntary Contribution Games: Efficient Private Provision of Public Goods.'' *Economic Inquiry* 29 (2): 351–66.

Barrett, S. 1994. ''Self-enforcing International Environmental Agreements.'' *Oxford Economic Papers* 46 (5 Supp.): 878–94.

Baumol, W. J., and W. E. Oates. 1988. *The Theory of Environmental Policy*. Cambridge, U.K.: Cambridge University Press.

Becker, N., and K. W. Easter. 1999. ''Conflict and Cooperation in Managing International Water Resources Such as the Great Lakes.'' *Land Economics* 75 (May): 233–45.

Botteon, M., and C. Carraro. 1997. ''Burden-Sharing and Coalition Stability in Environmental Negotiations with Asymmetric Countries.'' In *International Environmental Agreements: Strategic Policy Issues*, ed. C. Carraro, 26–55. Cheltenham, U.K.: Edward Elgar Pub.

Brau, R., C. Carraro, and G. Golfetto. 2000. ''Endogenous VAs, Coalition Formation and Market Structure.'' Paper presented at the CAVA workshop on ''Voluntary Approaches, Competition and Competitiveness,'' May 25–26, Milan, Italy.

Carraro, C., and F. Lévêque. 1999. ''Introduction: The Rationale and Potential of Voluntary Approaches.'' In *Voluntary Approaches In Environmental Policy*, ed. C. Carraro and F. Lévêque, 1–15. Dordrecht: Kluwer Academic Publishers.

Carraro, C., and D. Siniscalco. 1993. ''Strategies for the International Protection of the Environment.'' *Journal of Public Economics* 52 (3): 309–28.

Cavaliere, A. 1998. ''Voluntary Agreements, Overcompliance and Environmental Reputation.'' Paper presented at World Congress of Environmental and Resource Economists. June, Venice, Italy.

Chidiak, M. 1999. ''Choosing a Tax, a Voluntary Agreement or a Policy-Mix: A Model Based on the Danish CO_2 Scheme.'' Paper presented at CAVA workshop on ''The Efficiency of Voluntary Approaches in Environmental Policy—What Can be Derived From Theory?'' May 25–26, Copenhagen, Denmark..

Commission of the European Communities (CEC). 1996. *On Environmental Agreements. Communication from the Commission to the Council and the European Parliament*. Brussels.

d'Aspremont, C., and J. J. Gabszewicz. 1986. ''On the Stability of Collusion.'' In *New Developments in the Analysis of Market Structure*, ed. J. E. Stiglitz and G. F. Matthewson, 243–61. Cambridge, Mass.: MIT Press.

d'Aspremont, C., A. Jacquemin, J. J. Gabszewicz, and J. A. Weymark. 1983. ''On the Stability of Collusive Price Leadership.'' *Canadian Journal of Economics* 16 (1): 17–25.

Davies, J. C., and J. Mazurek. 1996. *Industry Incentives for Environmental Improvement: Evaluation of US Federal Initiatives*. Prepared for Global Environmental Management Initiative (GEMI). Washington D.C.: Resources for the Future.

Delmas, M., and A. Keller. 2005. ''Free-Riding in Voluntary Environmental Programs: The Case of US EPA's WasteWise Program.'' *Policy Sciences* 38 (2–3): 91–106.

Dixit, A., and M. Olson. 2000. ''Does Voluntary Participation Undermine the Coase Theorem?'' *Journal of Public Economics* 76 (3): 309–35.

Donsimoni, M-P., N. S. Economides, and H. M. Polemarchakis. 1986. ''Stable Cartels.'' *International Economic Review* 27 (2): 317–27.

Esty, D. C. 1997. ''Clean and Competitive: Business-Led Environmental Management.'' In *Business-led Initiatives in Environmental Management: The Next Generation of Policy?* ed. S. S. Batie, D. E. Ervin, and M. A. Schultz, 37–58. Special Report 92, Proceedings of Preconference Workshop to the American Agricultural Economics Association Annual Meeting, Toronto.

European Environmental Agency (EEA). 1997. *Environmental Agreements: Environmental Effectiveness*. Environmental Issue Series No. 3, vol. 1–2. Copenhagen.

Gaines, S. F., and K. Mfodwo. 1996. ''Voluntary Agreements in Environmental Regulation with Particular Reference to New Zealand (Voluntary Agreements I).'' *The Australian Journal of Natural Resources Law and Policy* 3 (2): 271–338.

Goodin, R. E. 1986. ''The Principle of Voluntary Agreement.'' *Public Administration* 64 (4): 435–44.

Jaffe, A., S. R. Peterson, P. R. Portney, and R. Stavins. 1995. ''Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?'' *Journal of Economic Literature* 33 (1): 132–63.

Jochem, E., and W. Eichhammer. 1999. ''Voluntary Agreements as an Instrument to Substitute Regulations and Economic Instruments: Lessons from the German Voluntary Agreements on CO_2 Reduction.'' In *Voluntary Approaches in Environmental Policy*, ed. C. Carraro and F. Lévêque, 209–27. Dordrecht: Kluwer Academic Pub.

Khanna, M. 2001. "Economic Analysis of Non-Mandatory Approaches to Environmental Protection." *Journal of Economic Surveys* 15 (3): 291–324.

Khanna, M., and L. Damon. 1999. "EPA's Voluntary 33/50 Program: Impact on Toxic Releases and Economic Performance of Firms." *Journal of Environmental Economics and Management* 37 (1): 1–25.

Lévêque, F., and A. Nadaï. 1995. "A Firm's Involvement in the Policy-Making Process." In *Principles of Environmental and Resource Economics*, ed. F. Henk, H. L. Gabel, and H. Opschoor, 299–327. Cheltenham: Edward Elgar Pub.

Marks, M. B., and R. T. A. Croson. 1999. "The Effect of Incomplete Information in a Threshold Public Goods Experiment." *Public Choice* 99 (1–2): 103–18.

Maxwell, J. W., T. P. Lyon, and S. C. Hackett. 2000. "Self-Regulation and Social Welfare: The Political Economy of Corporate Environmentalism." *Journal of Law and Economics* 43 (2): 583–618.

Millock, K. 1999. "The Combined Use of Taxation and Voluntary Agreements for Energy Policy." Paper presented at CAVA workshop on "The Efficiency of Voluntary Approaches in Environmental Policy—What Can be Derived From Theory?" May 25–26, Copenhagen, Denmark.

Millock, K., and F. Salanié. 2000. "Are Collective Environmental Agreements Ever Effective?" Working paper, EIRED and LEERNA.

Nyborg, K. 2000. "Voluntary Agreements and Non-Verifiable Emissions." *Environmental and Resource Economics* 17 (2): 125–44.

Organisation for Economic Co-operation and Development (OECD). 1999. *Voluntary Approaches for Environmental Policy: An Assessment*. Paris.

Rapoport, A. 1985. "Provision of Public Goods and the MCS Experimental Paradigm." *American Political Science Review* 79 (1): 148–55.

Rondeau, D., W. D. Schulze, and G. L. Poe. 1999. "Voluntary Revelation of the Demand for Public Goods Using a Provision Point Mechanism." *Journal of Public Economics* 72 (3): 455–70.

Segerson, K., and N. L. Dawson. 2001. "Environmental Voluntary Agreements: Participation and Free Riding." In *Environmental Contracts: Comparative Approaches to Regulatory Innovation in Europe and the United States*, ed. E. Orts and K. Deketelaere, 369–88. Dordrecht: Kluwer Law International.

Segerson, K., and N. Li. 1999. "Voluntary Approaches to Environmental Protection," In *The International Yearbook of Environmental and Resource Economics 1999/2000*, ed. F. Henk and T. Tietenberg, 273–306. Cheltenham, U.K.: Edward Elgar Pub.

Segerson, K., and T. J. Miceli. 1998. "Voluntary Environmental Agreements: Good or Bad News for Environmental Quality?" *Journal of Environmental Economics and Management* 36 (2): 109–30.

———. 1999. "Voluntary Approaches to Environmental Protection: The Role of Legislative Threats." In *Voluntary Approaches in Environmental Policy*, ed. C. Carraro and F. Lévêque, 105–20. Boston: Kluwer Academic Pub.

Segerson, K., and J. Wu. 2006. "Nonpoint Pollution Control: Inducing First Best Outcomes through the Use of Threats." *Journal of Environmental Economics and Management* 51 (2): 165–84.

Smart, B., ed. 1992. *Beyond Compliance: A New Industry View of the Environment*. Washington, D.C.: World Resource Institute.

Stewart, R. B. 1993. "Environmental Contracts and Covenants: A United States Perspective." In *Environmental Contracts and Covenants: New Instruments for a Realistic Environmental Policy?*, ed. J. M. van Dunné, 159–81. Proceedings of an International Conference held in Rotterdam, October 14–16, 1992.

Stranlund, J. K. 1995. "Public Mechanisms to Support Compliance to an Environmental Norm." *Journal of Environmental Economics and Management* 28 (2): 205–22.

Van de Kragt, A. J. C., J. M. Orbell, and R. M. Dawes. 1983. "The Minimal Contributing Set as a Solution to Public Goods Problems." *American Political Science Review* 77 (1): 112–22.

Videras, J., and A. Alberini. 2000. "The Appeal of Voluntary Environmental Programs: Which Firms Participate and Why?" *Contemporary Economic Policy* 18 (4): 449–61.

Wu, J., and B. A. Babcock. 1995. "Optimal Design of a Voluntary Green Payment Program Under Asymmetric Information." *Journal of Environmental Economics and Management* 20 (2): 316–27.

———. 1996. "Contract Design for the Purchase of Environmental Goods from Agriculture." *American Journal of Agricultural Economics* 78 (4): 935–45.