Voluntary vs. Mandatory Approaches to Nonpoint Pollution Control:

Complements or Substitutes?

by

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Non-Technical Summary

The economic literature on the control of nonpoint sources of pollution (NPP) has focused on the design of policies based on mandatory regulations or taxes. Yet, historically, control of NPP has focused mostly on the use of voluntary, cost-sharing mechanims to induce farmers to invest in environmentally-friendly production practices. Recently, however, questions have arisen regarding whether sole-reliance on the use of voluntary programs will be sufficient to achieve water quality goals. Thus, attention has turned to possible mandatory controls. Concern has been expressed, however, about the information-intensiveness of mandatory policies that are able to achieve water quality targets at minimum cost. This has lead to increased interest in the use of "flexible" incentive mechanisms for controlling NPP.

This paper proposes and analyzes a policy approach that combines both voluntary and mandatory features. The proposal embodies "flexible" incentives in the sense that it seeks to achieve water quality goals efficiently (i.e., at least cost) but without incurring the high information costs typically associated with cost-minimizing mandatory policies. The proposal includes a temporary period during which farmers are given an opportunity to meet a given water quality goal voluntarily, with the explicit threat that if the goal is not met within that time, farmers may face mandatory controls. A model is developed to determine the conditions under which a regulator might want to use such a "combined" policy, and whether the policy can be implemented without the need for farm-specific information about pollution and/or production characteristics of individual farmers. The results suggest that, under a (credible) threat of imposition of a mandatory control that will induce cost-minimizing abatement decisions, the regulator can use a uniform subsidy rate (i.e., a rate that does not depend on farm characteristics) to induce participation in a voluntary program to achieve a given water quality goal. However, a voluntary program of this type might or might not be lead to higher social welfare.

Technical Summary

This paper develops a simple economic model of the interaction between a regulator and farmer that allows us to analyze the use of a policy that combines a voluntary, cost-sharing approach to improving water quality with a background threat of imposition of mandatory controls or taxes if the voluntary approach is unsuccessful in meeting a prespecified water quality goal. In particular, we use the model to examine the conditions under which a welfare-maximizing regulator would want to offer such a policy to farmers, and whether the regulator can use such a policy to induce cost-minimizing abatement decisions without the need for farm-specific information about pollution-related characteristics that would be needed to implement first best mandatory policies (such as ambient taxes). We first consider the simpler case where there is a single farm in a given watershed. We then extend the analysis to consider multiple farms, and ask whether the policy can be designed to avoid free-riding in this context. The results suggest that, under a (credible) threat of imposition of a mandatory mechanism that will induce cost-minimizing abatement decisions, the regulator can use a uniform subsidy rate (i.e., a rate that does not depend on farm characteristics) to induce participation in a voluntary program to achieve a given water quality goal. Thus, it is possible to induce first-best abatement decisions by heterogeneous farms without knowing farm-specific characteristics or tailoring the subsidy rate to the farm type. Whether a welfare-maximizing regulator would want to establish a voluntary program of this type depends on the magnitude of the transactions costs associated with implementing a first-best mandatory instrument, the likelihood that a mandatory approach would be imposed if there is no voluntary approach or if a voluntary approach is unsuccessful, and the social cost of funds used to finance any subsidy that is paid for participation in a voluntary approach.

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I. INTRODUCTION

While concerns about pollution control originally focused on point sources of pollution, attention has now turned to the control of diffuse or nonpoint pollution sources. A notable example of nonpoint source pollution (NPP) is the contamination of surface water from the runoff of agricultural chemicals. In many locations agriculture is a significant source of NPP. Hence, much of the literature on NPP is in the context of agricultural water pollution.

Control of NPP is hampered by the fact that emissions of pollutants are not readily observable given their diffuse nature,[1] which implies that traditional policy instruments based on emissions (e.g., emissions taxes or regulation) cannot be used in this context. This has lead economists to consider alternative mandatory instruments that can be used to control NPP. These include input taxes, input regulations, ambient taxes, random fines, rank order tournaments, and type-specific contracts (Griffin and Bromley 1982; Shortle and Dunn 1986; Segerson 1988, Xepapadeas 1991, 1992, 1995; Cabe and Herriges 1992; Herriges et al. 1994; Govindasamy et al. 1994; and Shortle and Abler 1994). Instruments that provide flexible incentives (such as ambient taxes) can be used to induce first-best control of NPP (Segerson 1988). However, because farmers in a given watershed are often very heterogeneous with respect to both their production and pollution characteristics, cost-minimizing abatement levels will vary across farms. Hence, information about farm-level charactertistics is needed to design these first-best policy instruments. They have thus been criticized as being likely to involve high information and/or transactions costs (e.g., Cabe and Herriges 1992; Batie and Ervin 1997).This has led some to suggest the use of second best policy instruments instead (Helfand and House 1995; Wu et al. 1995; Wu and Babcock 1996c). Use of these second best instruments involves a tradeoff. While transaction and

[1] For an overview of issues relating to nonpoint source pollution from agriculture, see Braden and Segerson (1993) and Tomasi, Segerson and Braden (1994).

information costs may be lower, in general, these instruments fail to allow for heterogeneity across farms or for other farmer decisions that affect water quality. Thus, they do not achieve the targeted water quality level at the minimum total abatement cost.

Althought the theoretical debate on instrument choice to control agricultural NPP has focused on "stick" instruments that control pollution by imposing some restriction or penalty (regulation or tax) on farmers, historically such "mandatory" approaches have seldom been used in the U.S.[2] Instead, agricultural water quality policy has been based on the use of "carrot" instruments designed to entice farmers to use environmentally-friendly practices voluntarily or to participate in voluntary programs aimed at improving water quality (Ribaudo and Caswell 1997). For example, the 1996 Federal Agricultural Improvement and Reform Act (FAIR) recently established the Environmental Quality Incentives Program (EQIP), which consolidated under one program a number of existing subsidy programs that provide financial incentives for farmers to reduce pollution (Ogg and Kuch 1997).[3]

The varying success rates of voluntary programs has led some to question whether reliance on them will adequately control agricultural pollution (Ribaudo and Caswell 1997), suggesting the need for mandatory controls or incentives to ensure adequate environmental protection. Yet, as noted above, mandatory controls[4] generally have drawbacks in terms of inflexibility (in the case of second-best instruments) or high transaction or information costs (for first-best instruments). Thus, neither purely voluntary programs nor mandatory approaches by themselves seem to offer a desirable "solution" to agricultural NPP.

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[2] Mandatory controls are, however, commonplace in other sectors, such as the industrial sector. For example, both the Clean Water Act and the Clean Air Act are based on a regulatory approach to pollution control.

[3] For other discussions of the use of subsidies to reduce agricultural sources of water pollution, see Braden and Lovejoy (1990), Norton et al. (1994), Lohr and Park (1995), Bosch et al. (1995), Wu and Babcock (1995), Hardie and Parks (1996), Wiebe et al. (1996), Wu and Babcock (1996a), Babcock et al. (1996), and Cooper and Keim (1996).

[4] Henceforth, we use the term "mandatory controls" to refer both to mandatory regulations or restrictions and tax-based policies such as ambient taxes or input taxes.

There is, however, an alternative role for voluntary and mandatory approaches to NPP, namely, as complementary instruments to be used together rather than as substitutes to be used in isolation. As has become apparent in the context of point source pollution, the threat of the imposition of mandatory controls can be an effective mechanism for inducing firms to participate in voluntary agreements (Commission of the European Communities 1996; Segerson and Miceli 1997). Voluntary approaches to pollution control have been increasingly used for control of point source pollution (Commission of the European Communities 1996; Segerson and Li, forthcoming). Advocates of voluntary approaches in that context note their potential to provide greater flexibility in meeting environmental quality goals and hence lower compliance costs. They also point to the potential savings in transactions costs (Commission of the European Communities 1996). To realize these potential costs savings, however, firms must be induced to participate. In many cases, inducement to participate in voluntary programs stems from a background threat of regulation if the voluntary approach is unsuccessful in achieving environmental goals. Segerson and Miceli (1998) develop a simple model of voluntary agreements between regulators and firms, where the inducement to participate can come either from a "carrot" (subsidy) or "stick" (threat of regulation). They show that in such a context the agreement under the voluntary approach might or might not lead to more environmental protection than might have been achieved under a mandatory approach, depending on the likelihood that regulation would be imposed if a voluntary approach is unsuccessful, the social cost of funds used for subsidies, and the relative bargaining power of the regulator and the firm. When used as a background threat, the role of mandatory controls is not as an end in and of themselves (i.e., a policy to be actually implemented), but rather as a means toward an end (a means of inducing adequate participation in a lower cost voluntary approach). Since the objective is to use the mandatory controls as a threat but hopefully never have to actually implement them,[5] the concerns about the drawbacks of mandatory approaches (due to

[5] The regulator must, however, be prepared to implement the threat if necessary. Otherwise, the threat would not be credible.

inflexibility or high information/transaction costs) are reduced.

A few states have experimented with the use of mandatory approaches as threats to be invoked if reliance on voluntary measures is insufficient to control nonpoint source pollution, and the threat of regulation has been shown to create an incentive for farmers to alter their production practices (Ribaudo and Caswell 1997). Yet to date the economic literature on NPP has not considered the possible use of both voluntary and mandatory approaches as complementary parts of a policy package.[6] As noted above, Segerson and Miceli (1998) develop a model of this type in the context of point source pollution, where the regulator negotiates with an individual firm (or an industry representative) over the level of abatement under the agreement. Their focus is on the negotiated level of abatement that emerges under the agreement. They do not consider an approach under which the regulator sets an environmental quality target and then seeks participation in a program to achieve that target, as is typical in the case of NPP.

This paper develops a simple economic model of the interaction between a regulator and farmer that allows us to analyze the use of a policy that combines a voluntary, cost-sharing approach to improving water quality with a background threat of imposition of mandatory controls or taxes if the voluntary approach is unsuccessful in meeting a prespecified water quality goal. In particular, we use the model to examine the conditions under which a welfare-maximizing regulator would want to offer such a policy to farmers, and whether the regulator can use such a policy to induce cost-minimizing abatement decisions without the need for farm-specific information about pollution-related

[6] Some studies do consider tax/subsidy instruments under which the farmer would receive a tax or subsidy, depending on whether actual water quality fell below or above some prespecified standard (Segerson 1988), or where one farmer would be taxed while the others would be subsidized (Xepapadeas 1991). However, with these instruments, the subsidy part is not designed to induce voluntary participation in an environmental program. In addition, Wu and Babcock (1996b) compare the use of voluntary and mandatory approaches to NPP, but they treat the two as alternatives and do not consider a policy package under which the two are combined.

characteristics that would be needed to implement first best mandatory policies (such as ambient taxes).[7] We first consider the simpler case where there is a single farm in a given watershed. We then extend the analysis to consider multiple farms, and ask whether the policy can be designed to avoid free-riding in this context. The results suggest that, under a (credible) threat of imposition of a mandatory mechanism that will induce cost-minimizing abatement decisions, the regulator can use a uniform subsidy rate (i.e., a rate that does not depend on farm characteristics) to induce participation in a voluntary program to achieve a given water quality goal. Thus, it is possible to induce first-best abatement decisions by heterogeneous farms without knowing farm-specific characteristics or tailoring the subsidy rate to the farm type. Whether a welfare-maximizing regulator would want to establish a voluntary program of this type depends on the magnitude of the transactions costs associated with implementing a first-best mandatory instrument, the likelihood that a mandatory approach would be imposed if there is no voluntary approach or if a voluntary approach is unsuccessful, and the social cost of funds used to finance any subsidy that is paid for participation in a voluntary approach.

II. AN OVERVIEW OF THE MODEL

We consider first the case of a single farmer whose agricultural activities can pollute a nearby waterbody. The farmer can engage in observable abatement practices that reduce water pollution, or, equivalently, increase ambient water quality in the waterbody. These include use of buffer strips, reduced tillage, manure storage facilities, land retirement and other practices that reduce erosion and runoff.[8] Let $a=(a_1,...,a_m)$ denote the vector of abatement practices. We assume that use of these

[7] While ambient taxes can be designed to induce "first-best" levels of abatement that balance marginal benefits and marginal costs of abatement, our interest below is in inducing cost-minimizing abatement, given an exogenous water quality standard. Our analysis is thus in the spirit of the "standards" approach discussed in Baumol and Oates (1988). Therefore, throughout the remainder of the paper, our use of the term "first-best" refers to "cost-minimizing" and does not imply a balancing of marginal benefits and costs. See also footnote 11.

[8] The farmer may also be able to engage in other abatement practices that are not readily observable (or monitored) by a regulator, such as changes in the timing and care taken in applying

practices in one period commits the farmer to their use for some time in the future as well, due, for example, to irreversible investment or contractual commitments.[9]

Expected ambient water quality, denoted x, is a function of the abatement practices used and the physical characteristics of the farm (e.g., the steepness of the fields and/or the proximity to the waterbody), denoted Θ, where $\Theta \in [\Theta_{min},\Theta_{max}]$.[10] Thus, x=x(a,Θ), where $\partial x/\partial a_i \geq 0$ and $\partial x/\partial \Theta \leq 0$. We assume that Θ is known to the firm at zero cost, and can be "observed" by the regulator at some positive cost. Without expending resources to observe Θ, however, the regulator knows only the probability distribution of Θ.

We assume that there is some exogenously set target level of water quality, denoted x_s, determined by a criterion such as "fishable and swimmable" or by the level necessary to support some desirable activity (e.g., salmon spawning).[11] The regulator takes this target as given, and, ceteris paribus,

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fertilizers and pesticides. In the context of the model, lack of observability implies that the regulator cannot readily subsidize these practices. If activities of this type are an important component of the cost-minimizing abatement vector, then the effectiveness of the proposal examined here would be reduced. In the extreme case where the cost-minimizing vector involves only activities that cannot be observed at all ex post, the effective subsidy rate would always be zero (the regulator would not be able to subsidize unobservable actions) and hence the regulator would not be able to use this mechanism to induce participation in a voluntary approach (see (8) with s=0).

[9] Clearly, the construction of manure storage facilities involves a fixed investment. In addition, land retirements are often committed to for some period of time, as under the Conservation Reserve Program. However, tillage practices can be easily changed annually. Our main goal in assuming irreversibility in the abatement decision is to preclude the possibility that a farmer would choose to meet a water quality standard voluntarily in the first period but then fail to do so in the second period. In other words, we assume that if he engages in practices sufficient to ensure that the standard is met in period one, he will continue to engage in those same practices in period two. We thus do not consider the possibility of future non-compliance.

[10] It is well-recognized that actual water quality will depend on a and Θ as well as on other random variables such as weather (e.g., Segerson, 1988). The expected level of water quality then depends on the distribution of the weather variable. However, since we state the policy goal as one of meeting a water quality standard on average over some period rather than at every instant in time, the daily variability attributable to weather is not a key part of the analysis. Thus, for simplicity of notation, we suppress the weather variable.

[11] Alternatively, the choice of the target might have been based on a balancing of benefits and costs. However, this would require that the regulator have information about minimum abatement costs, which we assume he can only obtain at some cost. Thus, in order to set the standard the

wants to induce or impose a vector of abatement activities that ensures that $x(a,\Theta) \geq x_s$ at least cost.[12]

Let the cost-minimizing abatement vector be denoted $a^*(x_s,\Theta)$, i.e., $a^*(x_s,\Theta)$ solves

$$\text{minimize} \quad C(a) \qquad (1)$$

$$\text{subject to} \quad x(a,\Theta) \geq x_s,$$

where C(a) is the cost of the abatement vector a. Then $C^*(x_s,\Theta)=C(a^*(x_s,\Theta))$ is the minimum cost of meeting the standard, given Θ, where $\partial C^*/\partial x_s>0$ and $\partial C^*/\partial\Theta>0$. Note that, when the regulator does not know Θ, he does not know a^* either. However, since a is observable and the regulator is assumed to know the cost function, ex post (i.e., after a has been chosen) he can determine the actual costs incurred by the farmer.

As noted above, policy instruments based on mandatory approaches may or may not result in cost-minimizing abatement choices, depending on the specific instrument used. For example, while ambient taxes induce cost-minimizing abatement choices (Segerson 1988), input taxes generally would not (Helfand and House 1995). Thus, the abatement cost of meeting the standard under mandatory controls, denoted $C_m(x_s,\Theta)$, will be no less and possibly more than the cost-minimizing level, i.e., $C_m(x_s,\Theta)) \geq C^*(x_s,\Theta)$. In addition, even when mandatory controls are flexible enough to result in cost-

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regulator would have to incur these costs. They could then be viewed as a sunk cost with regard to the choice of instrument to achieve the standard. In this case, the incremental information/transaction cost associated with the use of a first-best mandatory instrument would be zero. We show below that, if the first-best mandatory instrument does not entail any additional transaction costs, then reliance on a voluntary mechanism is never desirable since it involves use of costly subsidies. In addition, historically, water quality standards have not been based cost-benefit comparisons but rather on other criteria, such as those noted in the text (see Freeman 1990). For these reasons, we assume an exogenous target that is independent of farm type. This turns out to be important in "avoiding" the typical adverse selection problems associated with imperfect information about firm types. See further discussion below.

[12] This is in contrast to the model in Segerson and Miceli (1998), where the level of environmental quality under the voluntary approach is determined endogenously as a result of bargaining between the regulator and the firm. Here, we examine voluntary "programs" rather than voluntary "agreements", under the regulator unilaterally sets the program parameters (e.g., the subsidy rate) and the farmer simply chooses whether or not to participate in the program. Such programs are typical of voluntary approaches to agricultural sources of pollution control (see Introduction and references in footnote 3).

minimization, implementation of these flexible controls will generally entail information and/or transactions costs for the regulator, denoted T (Cabe and Herriges 1992; Batie and Ervin 1997). For example, to implement cost-minimizing farm-specific regulations, the regulator would have to incur costs to learn Θ. Given the information costs associated with using mandatory flexible mechanisms, we assume the total cost of meeting the standard under mandatory controls always exceeds the cost of meeting it voluntarily, i.e., $C_m(x_s,\Theta)+T>C^*(x_s,\Theta)$. Use of first-best mandatory instruments implies $C_m(x_s,\Theta)=C^*(x_s,\Theta)$ and $T>0$, while use of second best instruments (e.g., input taxes) implies $C_m(x_s,\Theta)>C^*(x_s,\Theta)$ and $T=0$. Henceforth, for simplicity of notation, we suppress the x_s argument in the cost functions, except where necessary to avoid confusion.

We consider a two-period model. At the beginning of the first period (denoted $t=1$), the regulator must choose whether or not to offer the following proposal to the farmer:

Proposal: The regulator agrees to give the farmer a one-period chance to meet the standard voluntarily. If at the end of the first period the standard has been met, mandatory controls will not be imposed. However, if the standard has not been met, there is some probability p, where $0\leq p\leq 1$, that mandatory controls will be imposed in the second period. The regulator also agrees to provide cost-sharing at a rate of s, where $0\leq s\leq 1$, to help to finance any abatement costs the farmer incurs under the voluntary program.

If the regulator makes the offer, the farmer must simply decide whether or not to participate in the voluntary program and undertake abatement practices that ensure that the standard will be met. If the regulator does not make the offer, i.e., if the voluntary program is not established, then there is no decision for the farmer to make. Instead, we simply assume that there is some probability q, where $0\leq q\leq 1$, that mandatory controls will be imposed. Note that the probabilities p and q can be exogeneously determined by, for example, the political will of the legislature. Small values would reflect a situation in which it is unlikely that the legislature would impose mandatory controls. If the likelihood of mandatory measures is greater once farmers have been given the opportunity to meet the standard voluntarily and failed to do so, then we would expect $p>q$. Alternatively, if the regulator has the authority to impose mandatory controls, these probabilities could be viewed as endogenous choice variables for the regulator. In this case, as long as the net benefit from the mandatory controls is positive, the regulator would always want to set these probabilities as high as possible. Thus, if they are endogenous we would expect p=q=1. Note that p=1 could also reflect a situation under which mandatory measures have already been put in place but an exemption from those measures has been granted if the farmers voluntarily meet the standard in the first period. An example of this type at the state level is the Everglades Forever Act, under which a Florida tax on cropland automatically increases every four years (up to a limit) unless farmers exceed an overall phosphorus reduction goal (Ribaudo and Caswell, 1997).

Figure 1 depicts the sequence of events and the payoffs for the farmer (F) and the regulator (R) associated with the different possible outcomes. The farmer's payoffs are defined in terms of aggregate expected costs incurred over the two periods.[13] The regulator's payoffs, on the other hand, are defined in terms of aggregate expected net benefits over the two periods. We assume that, when making decisions about policy approaches, the regulator is a net benefit maximizer. We thus abstract from public choice issues and other non-efficiency based factors that might in reality influence regulatory decisions. Incorporating these factors would introduce a potential distortion in the policymaking process, which is not the focus of this paper. Assuming the regulator is a net benefit maximizer implies that the regulator's payoffs can be interepreted as aggregate welfare.

The payoffs for the farmer and the regulator are as follows. If the regulator chooses not to offer a voluntary approach, then with probability q mandatory controls will be imposed in period 1 and remain in force in period 2.[14] If controls are imposed, over the two periods the firm will incur a cost of

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[13] For simplicity of notation, we ignore discounting. A discount factor could be easily included in the payoff functions.

[14] It is possible that the mandatory controls would only be implemented in period two instead. In this case, the payoffs for both the farmer and the regulator would be only one-half of those indicated in Figure 1. Alternatively, we could allow for the possibility that mandatory controls could be imposed in period two if they are not imposed in period one. The overall probability of imposition could be easily modified accordingly.

$2C_m(\Theta)$.[15,16] The expected aggregate net benefit for the regulator will be $2\{B\text{-}EC_m(\Theta)\text{-}T(1+\sigma)\}$, where E is the expectations operator over the distribution of Θ, B is the gross benefit from achieving a water quality level of x_s, and $\sigma \geq 0$ is the social cost of funds reflecting the need to finance the government's costs through distortionary taxation. With probability 1-q, no controls will be imposed and the payoffs for both parties will be equal to zero. Hence, the expected payoffs if the regulator does not offer the voluntary approach are

(2) $$2qC_m(\Theta)$$

and

(3) $$2q\{B\text{-}EC_m(\Theta)\text{-}T(1+\sigma)\}.$$

for the farmer and the regulator, respectively.[17]

On the other hand, if the regulator offers the voluntary program, then the farmer must choose whether or not to participate, i.e., to meet the standard voluntarily in period one. Note that, if he chooses to meet the standard voluntarily, then regardless of the level of the subsidy he will solve the problem in (1) and hence choose the cost-minimizing abatement vector and incur a before-subsidy cost

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[15] The payoffs for the farmer in Figure 1 assume that under the mandatory measures the farmer would incur only the cost of abatement. This would be true under a regulatory approach or, in equilibrium, under a properly designed ambient tax/subsidy policy. However, under other tax-based policies such as the use of input taxes, the total cost to the farmer would be the sum of abatement costs and tax payments.

[16] The "2" reflects an assumption that the periods are of equal length, which simplifies the notation. More generally, if costs and benefits are annual, the payoffs should be adjusted to reflect the number of years in each period.

[17] Note that both here and below we assume that the threat of imposition of mandatory controls is exogenous. Although we require that the threat be credible, i.e., that the regulator be better off imposing it than not imposing it, we do not consider the regulator's choice regarding which type of mandatory instrument to impose, if one is imposed. Thus, we do not endogenize the choice of the mandatory instrument to impose. As will be seen below, higher cost instruments (i.e., second-best instruments) will require smaller subsidies. Hence, in choosing a mandatory instrument, a welfare-maximizing regulator would balance the compliance cost gains from choosing a first-best instrument against the higher subsidy costs that would be incurred in order to induce participation. Thus, a second-best instrument (in terms of compliance costs) may in fact have lower total costs than a first-best instrument. Nonetheless, we show below that only a first-best instrument yields a uniform minimum subsidy rate.

of $C^*(\Theta)$ during each period. Thus, given participation, the level of the subsidy does not distort his abatement decision.[18] With a cost-share rate of s, his aggregate net cost over the two periods will be

$$2C^*(\Theta)(1-s). \tag{4}$$

Alternatively, if the farmer chooses not to participate in the voluntary program, he will have no incentive to invest in any abatement practices and hence will incur no costs during period one. However, with probability p mandatory controls will be imposed in period two. Thus, the expected cost for the farmer over the two periods is simply

$$pC_m(\Theta). \tag{5}$$

Consider next the payoffs for the regulator if he offers a voluntary approach with a subsidy rate of s. If the farmer chooses to participate in the voluntary program and hence meet the standard voluntarily, the payoff to the regulator over the two periods is

$$2\{B-EC^*(\Theta^*\Theta\in\Phi(s))(1+\sigma s)\}, \tag{6}$$

where the expectation in (6) is conditional on Θ being in the set of all Θ that participate given s, denoted Φ(s). As noted above, a strictly positive σ could reflect the deadweight loss associated with distortionary taxation necessary to raise the revenue for the subsidy.

Similarly, if the farmer does not participate in the voluntary program, the regulator receives no net benefits in period one and then with probability p receives the net benefits from mandatory controls in period two. If the transaction costs T must be financed with distortionary taxation, then the regulator's expected payoff over the two periods will be

[18] As a result, the regulator has no incentive to manipulate the choice of the subsidy rate in an effort to affect the farmer's abatement decisions, and the firm has no incentive to "hide" its type (by masquerading as a different type), given participation. This distinguishes the problem here from a typical adverse selection problem, where one type of firm must be paid information rents to prevent it from masquerading as a different type. As noted in footnote 11, this hinges on the assumption of an exogenous water quality standard that is independent of farm type. If the target levels were type-specific, the regulator would not automatically be able to satisfy both the participation and incentive compatibility constraints for all types by setting a uniform subsidy rate at the minimum level that induces participation.

(7) $$p\{B-EC_m(\Theta^*\Theta\in\Phi_{-1}(s))-T(1+\sigma)\},$$

where $\Phi_{-1}(s)$ is the complement of $\Phi(s)$.

Note that the right hand branch of the tree in Figure 1 represents the policy of using voluntary and mandatory (or "carrot" and "stick") approaches in combination, i.e., as complements, to achieve the water quality standard. However, the model embodies the conventional approach of viewing these as alternatives or substitutes as a special case. In particular, if p=0 and q=1, the model depicts the conventional choice between purely mandatory and purely voluntary approaches.

III. IS A VOLUNTARY PROGRAM DESIRABLE?

We can now examine the conditions under which a farmer would choose to participate in a voluntary program if one were available, and, given this, the conditions under which a regulator would choose to offer the voluntary program. A comparison of (4) and (5) implies that, if a voluntary program were available, the farmer would choose to participate in it, i.e., choose to meet the standard voluntarily, if and only if

(8) $$2C^*(\Theta)(1-s) \leq pC_m(\Theta).$$

Clearly, whether or not the farmer will participate depends on the subsidy rate, the likelihood of mandatory controls, and the cost of the mandatory control that is threatened. The shaded area in Figure 2 depicts the combinations of s and p that would induce participation if the threatened mandatory instrument is first best (C_m=C^*). If the threatened instrument is second best (so that C_m>C^*), the boundary of this region rotates downward, as shown in Figure 2. This boundary determines the minimum subsidy rate, s_{min}, that would be necessary to induce a farmer of type Θ to participate in the voluntary program, given by

(9) $$s_{min} = 1 - \{pC_m(\Theta)/2C^*(\Theta)\}.$$

Note that if p=0, then s_{min}=1 for all Θ regardless of the value of C_m. Without the threat of mandatory controls if the standard is not met, the farmer will not participate unless his costs of doing so are fully covered, i.e., there must be full cost sharing to induce participation.[19] However, for any $p>0$, farmers can be induced to participate with less than full cost sharing. More generally, the more likely it is that controls would be imposed, the smaller is the minimum subsidy rate necessary to induce participation ($\partial s_{min}/\partial p<0$). This implies that, if p can be chosen by the regulator (rather than being exogenously determined by other political factors), the regulator would clearly choose $p=1$ if subsidies are costly (i.e., if $\sigma>0$).

Note that if the mandatory controls are first best so that $C_m(\Theta)=C^*(\Theta)$, then

(10) $$s_{min} = 1 - p/2,$$

which is independent of Θ.[20] Thus, by threatening first best controls, the regulator is able to induce participation using a uniform subsidy rate. Since participation ensures cost-minimizing abatement decisions by firms, by combining a threat of first best controls with this uniform subsidy rate, the regulator can induce a first best outcome without the need for farm-specific information. Note, however, that although this outcome is first best in the sense of ensuring that the environmental quality standard is met at the lowest possible abatement costs, it is not necessarily the outcome that minimizes total social costs, including the social cost of the subsidy necessary to induce participation. As can be seen from (9) and Figure 2, by threatening a second best instrument, the regulator could reduce the subsidy necessary to induce participation. Thus, it is conceivable that total costs would be lower if the regulator instead chose to either (i) threaten second best controls and then incur the costs (T) necessary to learn θ so that a type-specific subsidy rate could be used (based on (9)), or (ii) threaten second best controls and set a uniform subsidy rate, implying that some but not all farmers might participate. In the latter case, the value of s could be chosen to maximize welfare, given the impact of that choice on both

[19] This is consistent with the results in Norton et al. (1994). Note that it assumes that there are no private gains to participation. Private gains might come in the form of improved environmental quality on the farm, which could directly benefit the farmer and his family, or public relations benefits from voluntary participation. Benefits of this type could be easily incorporated into the model.

[20] Similarly, if both C^* and C_m are linear in Θ, s_{min} will be independent of Θ.

the cost of the subsidy and the participation decision (see Appendix). Whether the threat of first best controls leads to lower social costs than either of these two alternatives depends on the cost functions, the distribution of θ, and the magnitudes of the parameters (p, T and σ). Rather than consider each case in turn, we focus below on the case where the regulator chooses to threaten first best controls. The main advantage of this threat is that the regulator can induce full participation with a uniform subsidy rate, i.e., without the need for farm-specific information. We recognize, however, that this may not always be the optimal "threat-subsidy" combination.

Since under the threat of first-best mandatory controls s_{min} is independent of Θ,[21] the regulator can guarantee participation by setting $s \geq s_{min}$ and guarantee that the farmer will not participate by setting $s < s_{min}$. Clearly, since subsidies are costly when σ>0, the regulator will never want to set $s > s_{min}$. Thus, the regulator will set s equal to s_{min} if at this subsidy rate the payoff from participation exceeds the payoff without participation. Otherwise, he will set $s < s_{min}$. We thus ask whether the regulator's payoff is higher at a subsidy rate of s_{min}, which ensures participation, or at a rate less than s_{min}, which ensures non-participation.[22] Without loss of generality, we assume that if the regulator sets $s < s_{min}$, he sets s=0.

(6) and (7) indicate that the regulator would prefer a subsidy rate of s_{min} and participation to a subsidy rate less than s_{min} with no participation if and only if

(11) $$2\{B-EC^*(\Theta^*\Theta\in\Phi(s_{min}))(1+\sigma s_{min})\} \geq p\{B-EC^*(\Theta^*\Theta\in\Phi_{-1}(0))-T(1+\sigma)\}.$$

Given (10), this condition becomes

(12) $$2\{B-EC^*(\Theta)(1+\sigma)\} \geq p\{B-[EC^*(\Theta)+T](1+\sigma)\}.$$

Note that the expectations in (12) are no longer conditional since $\Phi(s_{min})=\Phi_{-1}(0)$ is the set of all Θ.[23]

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[21] Clearly, s_{min} is also independent of Θ when p=0. Thus, the analysis here also applies to the case where there is no threat of mandatory controls if the voluntary program is unsuccessful in meeting the water quality target.

[22] This is equivalent to asking whether there exists a subsidy rate at which participation in the voluntary program is mutually beneficial.

[23] This equality technically requires that $s_{min}>0$. However, even if this were not true, the expectation on the right hand side of (12) would be unconditional since by definition all farmers must

For a given σ and p, (12) defines a function $T^*(\sigma,p)$, given by

(13) $$T^*(\sigma,p) = (1-2/p)(1+\sigma)\{B-EC^*(\theta)(1+\sigma)\},$$

such that the regulator prefers offering s_{min} if and only if $T \geq T^*$.[24] Since we assume throughout that the threat of imposition of mandatory controls is credible,

(14) $$B-EC^*(\theta)-T(1+\sigma) \geq 0,$$

and hence $B-EC^*(\theta) \geq 0$. Thus, $T^*(0,p)<0$ for all $p>0$. This implies that the regulator will always prefer participation at a subsidy rate of s_{min} to no participation if subsidies are costless. Clearly, with costless subsidies, the regulator prefers participation since it ensures that the net benefits of participation will be realized with certainty over two periods (rather than just with probability p over one period) and that the information costs associated with the imposition of first best mandatory controls will be saved. However, $\partial T^*/\partial\sigma>0$, and although $T^*<0$ for "small" values of σ (i.e., when $\sigma<(B/EC^*(\theta))-1$), $T^*>0$ for "large" values of σ. Thus, for sufficiently large σ, it is possible that the regulator would prefer participation for high values of T (i.e., when $T>T^*>0$) and prefer no participation for low values of T (i.e., when $T^*>T\geq 0$). This suggests that, unlike in previous studies where a voluntary agreement is always mutually beneficial given the potential cost savings,[25] here it may not be.

We now consider whether the regulator would want to offer a voluntary program in the first place. Clearly, if $T<T^*$, i.e., if a mutually beneficial voluntary program does not exist given σ and p, then the only motivation for offering a voluntary program would be to increase the likelihood of mandatory controls when the voluntary approach failed to meet the standard. Given that offering a voluntary

participate in the mandatory controls.

[24] We assume that when (12) holds as an equality, the regulator prefers to make the offer.

[25] For example, in Segerson and Miceli (1998), the potential cost savings for both the regulator and the firm ensures the existence of mutually beneficial agreements. However, in that context, the regulator is free to offer an abatement level under the voluntary agreement that is different from the level that might be imposed mandatorily, which provides the regulator with an additional degree of freedom in designing the voluntary approach. Here, the target level of environmental quality is exogenously fixed and is assumed to be the same under both the voluntary and the mandatory approaches.

approach would delay the possible imposition of mandatory controls by at least one period, it would be preferred if and only if $2q<p$. Clearly, this condition would never hold if the likelihood of imposition of controls is independent of whether the regulator has attempted a voluntary approach first, i.e., if $q=p$. However, it might hold if, for example, there is very little political will for imposition of mandatory controls by themselves (i.e., q is very low) but imposition is much more likely if the regulatory agency has shown that reliance on the voluntary approach (with subsidy levels that are acceptable to the regulator) is not sufficient to ensure that the target water quality level will be met.

Consider next the case where $T>T^*$, i.e., where under the voluntary program the regulator offers the minimum subsidy the farmer will accept (s_{min}). Then the regulator will prefer the voluntary approach if and only if

(15) $$2\{B-EC^*(\Theta)(1+\sigma-\sigma p/2)\} \geq 2q\{B-EC^*(\Theta)-T(1+\sigma)\}.$$

(15) defines a function $q^*(T,\sigma,p)$ such that the regulator prefers the voluntary approach if and only if $q \leq q^*$. Define

(16) $$T_{max} = EC^*(\theta)(1-p/2)\sigma/(1+\sigma).$$

T_{max} is the value of T at which $q^*=1$. Note that $T_{max}=0$ when $\sigma=0$, and $\partial T_{max}/\partial\sigma>0$. In addition, $q^*=p/2$ when $T=T^*$. Finally, q^* is increasing and convex in T.

The two functions $T^*(\sigma,p)$ and $q^*(T,\sigma,p)$ can be used to characterize the possible equilibrium outcomes. For given values of σ and p, Figure 3 depicts the possible equilibrium outcomes in q-T space for the case where $T^*>0$.[26] As indicated in the figure, the equilibrium outcome is a voluntary program if $T>T^*$ and $q<q^*$ (region D). If q exceeds q^* in the case where participation is preferred (region B) or p/2 in the case where participation is not preferred (region A), the regulator will not favor a voluntary program over possible mandatory controls, despite the potential cost savings from the voluntary approach. However, if the information costs associated with the mandatory approach are sufficiently

[26] If $T^*<0$, then regions A and C in Figure 3 would not exist, since T^* would lie to the left of the origin.

high and the likelihood that the legislature would impose mandatory controls in the absence of a voluntary initiative is sufficiently low, the regulator will prefer to develop a voluntary program and offer a subsidy rate that induces participation by all farmers (region D). Note that an increase in σ shifts both T^* and T_{max} to the left in Figure 3. In the extreme case where σ is zero, $T_{max}=0$ and the only remaining region is the right hand boundary of region D. Thus, as noted above, when $\sigma=0$ the regulator will always prefer a voluntary program with full participation, regardless of the value of q.

The results of this section can be summarized as follows. First, the magnitude of the cost-sharing subsidy that is necessary to induce participation in the voluntary program (and hence the cost of the program) is reduced when there is a background threat that mandatory controls will be imposed if the voluntary program is not successful in meeting the standard. The stronger is this threat (i.e., the larger is p), the lower is the necessary cost-sharing subsidy. Thus, the voluntary program is more likely to be desirable when it is combined with a strong threat of the imposition of mandatory controls. This implies that the combined use of "carrot" and "stick" approaches as a policy package (i.e., as complements rather than substitutes) can increase aggregate welfare.

Second, if the background threat is the imposition of first-best mandatory controls (such as ambient taxes), then the minimum subsidy necessary to induce participation in a voluntary program will be independent of farm type. In this case, the regulator can induce cost-minimizing abatement decisions by heterogeneous farmers without the need for site-specific information on farm type. Given the right subsidy level, the mere threat of acquiring that information and basing mandatory controls on it is sufficient to induce farmers to act on that information to ensure that the water quality standard is met voluntarily.

Third, despite the potential cost savings from use of a voluntary program, there does not necessarily exist a voluntary program that would achieve the exogenous environmental quality goal in a manner that is mutually beneficial. In other words, while the regulator may prefer a voluntary program that induces full participation, it is also possible that any subsidy rate that would induce participation would yield an expected welfare level that is less than the expected level from a purely mandatory approach. This is in contrast to previous results under which a mutually beneficial voluntary agreement could always be negotiated when the parties could bargain over the level of abatement. Here, the possibility that a voluntary program will be mutually beneficial increases when the transaction costs associated with mandatory instruments is high and the social cost of funds is low. In addition, as expected, the likelihood that a voluntary program increases welfare is higher when the likelihood that mandatory controls would be imposed in the absence of such a program is low.

IV. MULTIPLE FIRMS

In the above section we assumed that there was a single farm polluting a given waterbody. In many contexts there are likely to be several farms whose activities contribute to the ambient water quality in a neighboring lake or stream. We show in this section that a voluntary program coupled with a background threat can be used to induce cost-minimizing abatement decisions in this context as well. More specifically, we show that the regulator can choose a cost-sharing rate that induces cost-minimizing abatement as a Nash equilibrium and the likely outcome of a simple game among neighboring farmers. For simplicity, we limit the discussion to the case where the mandatory controls would be first-best controls (so that s_{min} is independent of Θ) and consider only the case of two farms.

We now let a_i and Θ_i denote the abatement vector and type for farm i, where i=1,2. We assume that each farmer knows not only his own type but the type of his neighbor. The expected ambient water quality is then $x=x(a_1,a_2,\Theta_1,\Theta_2)$. As before, the objective of the regulator is to meet an exogenously set water quality standard, x_s. The cost-minimizing abatement choices solve

$$\text{(17)} \qquad \text{minimize} \quad C(a_1) + C(a_2)$$

$$\text{subject to} \quad x(a_1,a_2,\Theta_1,\Theta_2) \geq x_s,$$

and are denoted $a_1^*(\Theta_1,\Theta_2,x_s)$ and $a_2^*(\Theta_1,\Theta_2,x_s)$. Let $C_i^*=C_i^*(\Theta_1,\Theta_2,x_s)=C(a_i^*)$ be the corresponding abatement costs for farmer i. Given the assumption that mandatory controls would be first-best, C_i^* also represents the cost of mandatory controls for farmer i. We consider three possible abatement choices for each farmer: (i) $a_i=0$, (ii) $a_i=a_i^*$, and (iii) $a_i=a_i^s$, where a_1^s is the solution to

$$\text{(18)} \qquad \text{minimize} \quad C(a_1)$$
$$\text{subject to} \quad x(a_1,0,\Theta_1,\Theta_2) \geq x_s,$$

and a_2^s is defined analogously. Thus, a_i^s is the abatement vector that minimizes farmer i's cost of meeting the standard, given that the other farmer does not invest in any abatement. Note that the outcome $(a_1,a_2)=(a_1^s,0)$ corresponds to the case where farmer 1 chooses to meet the standard on his own and farmer 2 "free rides" on farmer 1's abatement. Alternatively, farmer 1 could try to free ride on farmer 2. Clearly, if both farmers try to free ride, the standard will not be met.

Figure 4 depicts the payoff matrix for the possible combinations of a_1 and a_2. It should be clear that, regardless of the value of s, an outcome where $a_i=a_i^*$ and $a_j=0$ could never be a Nash equilibrium. If farmer j does not invest in any abatement, then farmer i will choose either to meet the standard on his own (i.e., choose a_i^s) or not to meet the standard and hence invest nothing (i.e., choose $a_i=0$). Similarly, an outcome where $a_i=a_i^s$ and $a_j=a_j^*$ or $a_j=a_j^s$ could never be a Nash equilibrium. If farmer i invests enough to meet the standard on his own, then farmer j will never invest a positive amount in abatement for any $s<1$. Thus, the only possible Nash equilibria are (0,0), $(a_1^s,0)$, $(0,a_2^s)$ and (a_1^*,a_2^*). Which of these is in fact a Nash equilibrium depends on the choice of s.

From the payoffs in Figure 4, it is clear that, if farmer i chooses a_i^*, then farmer j will choose a_j^* if and only if $pC(a_2^*) \geq 2C(a_2^*)(1-s)$, or, equivalently, if and only if $s \geq 1-p/2$.[27] Thus, by setting $s=1-p/2$, the regulator can ensure that (a_1^*,a_2^*) is a Nash equilibrium. Similarly, by setting $s<1-pC(a_j^*)/2C(a_j^s)$, he can ensure that when farmer 1 does not invest in any abatement (i.e., chooses $a_i=0$), farmer j will choose not to invest either (i.e., he will choose $a_j=0$). While the right hand side of this expression depends on farm type, since $C(a_j^*)<C(a_j^s)$, setting $s=1-p/2$ will satisfy the inequality for all Θ. Thus, by setting s=1-

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[27] This ensures that, when $a_i=a_i^*$, farmer j prefers $a_j=a_j^*$ to $a_j=0$. Clearly, he always prefers a_j^* to a_j^s when $a_i=a_i^*$.

p/2, the regulator can ensure that the only two Nash equilibria are (0,0) and (a_1^*,a_2^*). Note that, while there are other values of s that ensure this as well, s=1-p/2 is the lowest value of s that ensures it. If subsidies are costly, i.e., if $\sigma>0$, then the regulator would choose this level of s.

While both (0,0) and (a_1^*,a_2^*) are Nash equilibria when s=1-p/2, (a_1^*,a_2^*) pareto dominates (0,0).[28] Hence, if farmers are able to engage in "cheap talk," i.e., to communicate about their abatement plans (as would be expected in relatively small watersheds where farmers are neighbors), we would expect the solution to the game to be (a_1^*,a_2^*) (Rasmusen, 1994). Thus, by setting s=1-p/2 and threatening to impose first-best mandatory controls if the water quality standard is not met voluntarily, the regulator can induce both farmers to undertake cost-minimizing abatement activities voluntarily (and hence avoid free riding) without the need for costly farm-specific information.

VI. CONCLUSION

This paper has used a simple model of NPP to examine a policy under which voluntary and mandatory approaches to reducing water quality are used as complements in a policy package. We have shown that a regulator can use a voluntary, cost-sharing approach to induce farmers to undertake cost-minimizing abatement activities and that combining the voluntary program with a background threat of mandatory controls (taxes or regulations) can reduce the overall cost of the program by reducing the cost-sharing rate that is necessary to induce participation in the program. Depending on the social cost of funds and the transaction and other costs associated with the use of mandatory controls, this approach may be preferred by the regulator to sole reliance on the possible use of mandatory controls.

In addition, we have shown that, if the threatened mandatory instruments would yield cost-minimizing abatement decisions as well, then the optimal subsidy rate will be independent of farm type

[28] Given s=1-p/2, the game here is essentially a "ranked coordination" game, where the players need to coordinate on one of multiple Nash equilibria and both players have the same ranking of the pure strategy equilibria. See Rasmusen (1994).

and the regulator will not need information about farm-specific pollution characteristics to induce cost-minimizing abatement. Thus, by using cost-minimizing mandatory controls as a threat that is never actually implemented in equilibrium, the regulator can save the transaction/information costs that are likely to be associated with the sole reliance (and hence actual imposition) of first-best mandatory instruments.

Finally, we have shown that with a background threat of first-best mandatory instruments, a subsidy that is independent of farm type can be used to induce participation in a voluntary program (and hence cost-minimizing abatement decisions) even in the context of multiple farmers contributing to the ambient pollution of a given watershed. More specifically, a constant subsidy rate can generate participation by all farms as a Nash equilibrium, which is likely to be the outcome of the interaction between farmers if those farmers can communicate with each other (as is likely in the context of a small watershed). Thus, the voluntary program with the background threat can be designed to eliminate free rider incentives as well.

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Appendix

In this appendix, we consider the choice of a uniform subsidy rate when the background threat is the imposition of second best mandatory controls. In this case, the use of a uniform subsidy rate will not generally induce full participation in the program.

If the background threat is based on the use of mandatory controls that are not first best, then in general s_{min} will be a function of Θ. Note that

(A1) $$\partial s_{min}/\partial\Theta = -(p/2)(C^{*}\partial C_m/\partial\Theta - C_m\partial C^{*}/\partial\Theta)/C^{*2},$$

which can be positive or negative depending on the relative magnitudes of the terms in (A1). Assuming that (A1) is positive is equivalent to assuming that farmers with high pollution potential for whom the cost of meeting the standard voluntarily would be high ("high cost avoiders") will require a higher subsidy to induce participation in a voluntary program. Note that, if uniform mandatory controls are used (e.g., mandating the construction of manure storage facilities on all farms), the $\partial C_m/\partial\Theta=0$ and the expression in (A1) is unambiguously positive. We assume throughout that (A15) is positive.

While (8) was used above to define s_{min} for a given Θ, equivalently, for any given s, it implicitly defines a threshold level of Θ, $\Theta_p(s)$, such that a farmer with $\Theta\leq\Theta_p(s)$ would choose to participate in a voluntary program with a cost-sharing rate of s while a farmer with $\Theta>\Theta_p(s)$ would not, i.e., $\Phi(s)=[0,\Theta_p(s)]$. Note that an increase in s would increase Θ_p and hence increase the likelihood of participation.[29] Let $F(\Theta_p(s))=Prob\{\Theta\leq\Theta_p(s)\}$ denote the probability that a farmer will participate, where F is the probability distribution for Θ with $F'()=f()>0$. Then the expected payoff for the regulator if he offers a voluntary program with a uniform cost sharing rate of s is given by

(A2) $$W(s) = F(\Theta_p(s))\{2[B-EC^{*}(\Theta^{*}\Theta\leq\Theta_p(s))(1+\sigma s)]\} + (1-F(\Theta_p(s))\{p[B-EC_m(\Theta^{*}\Theta>\Theta_p(s))-T(1+\sigma)]\},$$

or, equivalently,

[29] This result hinges on the assumption that (A1) is positive.

(A3) $$W(s) = \int_{\Theta_{min}}^{\Theta_p} 2\{B-C^*(\Theta)(1+\sigma s)\}f(\Theta)d\Theta + \int_{\Theta_p}^{\Theta_{max}} \{p[B-C_m(\Theta)-T(1+\sigma)\}f(\Theta)d\Theta.$$

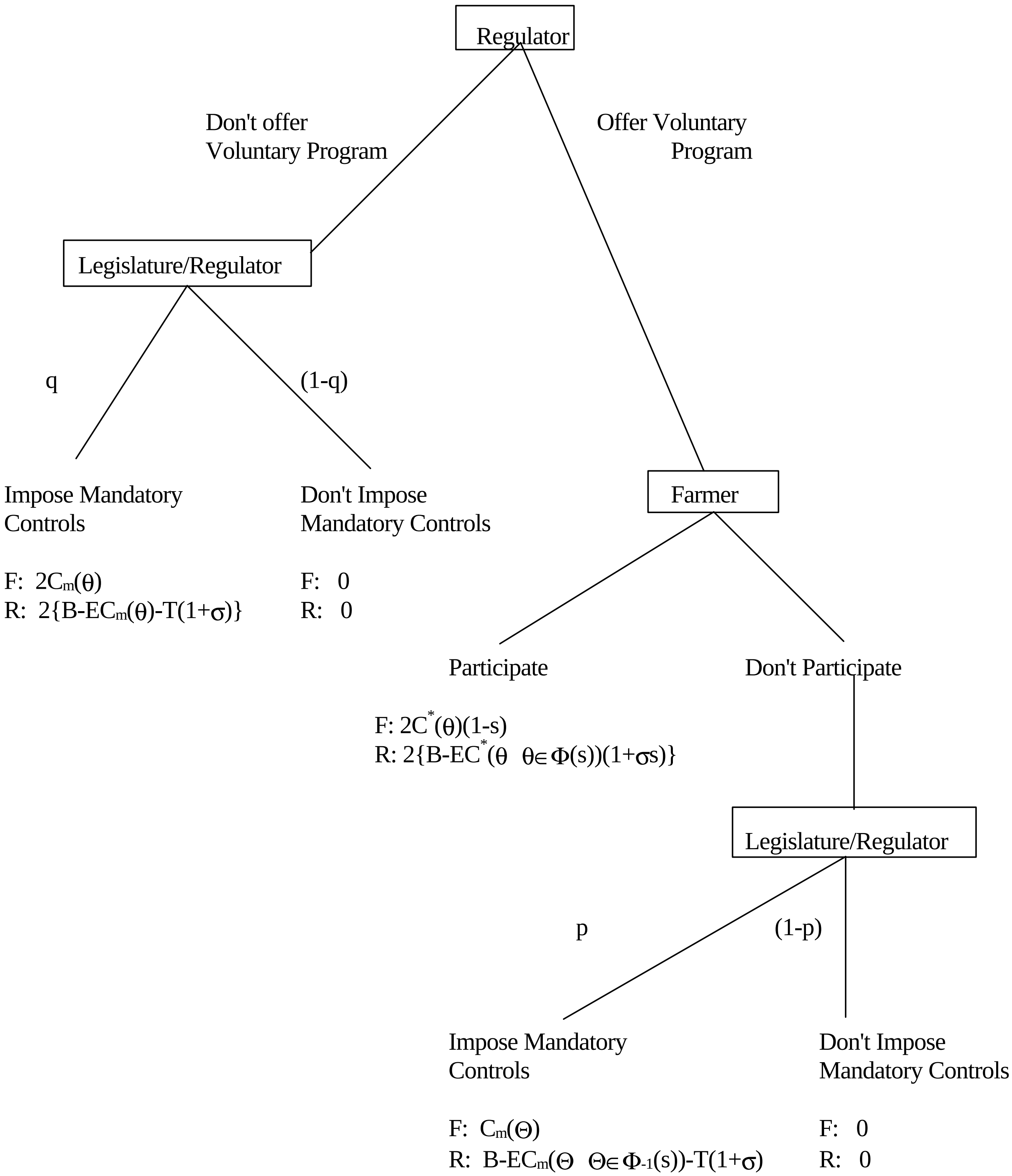
The regulator can choose s to maximize (A3), which yields the following first order condition:

(A4) $$W'(s) = \{2[B-C^*(\Theta_p(s))(1+\sigma s)] - p[B-C_m(\Theta_p(s))-T(1+\sigma)]\}\ f(\Theta_p(s))\ \partial\Theta_p/\partial s - \int_{\Theta_{min}}^{\Theta_p} 2C^*(\Theta)\sigma f(\Theta)d\Theta.$$

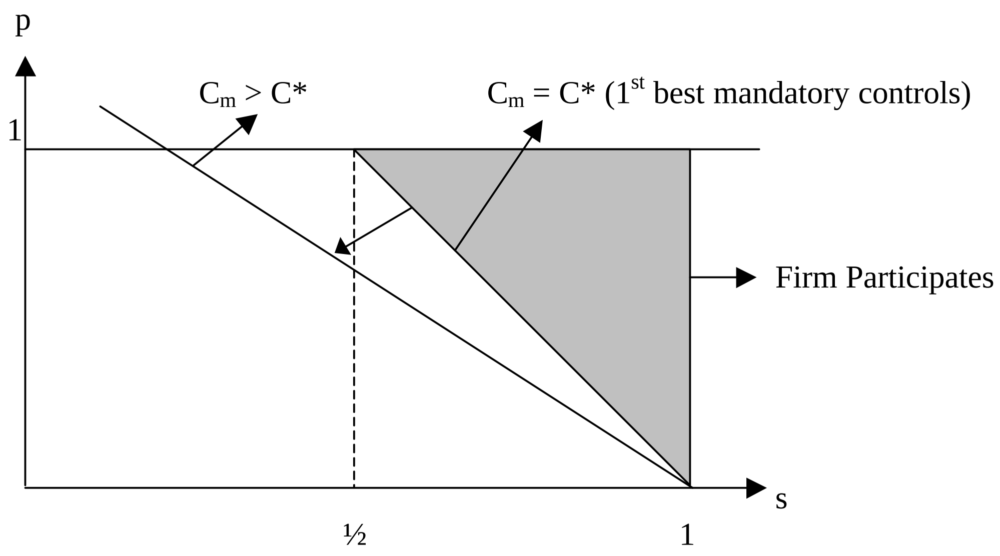
Note that, if s_{min} is independent of Θ, then choosing s to maximize (A2) is equivalent to setting $s=s_{min}$ (i.e., choosing s so that $F(\Theta_p(s))=1$) if the first term in curled brackets evaluated at s_{min} is greater than the second term in curled brackets evaluated at $s<s_{min}$, or setting $s<s_{min}$ (i.e., choosing s such that $F(\Theta_p(s))=0$) otherwise. Thus, the regulator's choice problem here is a generalization of the problem described in Section III.

The expression in (A3) can be used to identify two effects of an increase in the subsidy rate s. First, an increase in s will increase the range of Θ over which a farmer will participate in the voluntary program. If the expected payoff for the regulator given participation exceeds the expected payoff without participation, i.e., if the first integrand in (A3) exceeds the second integrand, then this increased participation will increase the regulator's expected payoff from offering the voluntary program. Secondly, an increase in s will increase the magnitude of the subsidy that must be paid. If $\sigma>0$ so that subsidies are costly, this will reduce the expected payoff for the regulator. A balancing of these two effects determines the optimal choice of s. Note that, even in this case where s_{min} varies across farmers, the regulator could ensure full participation with a single subsidy rate (i.e., without the need for detailed site specific information) by setting s equal to $s_{min}(\Theta_{max})$. If the subsidy rate is sufficiently high to ensure that the highest cost avoider would participate, it would be sufficient to induce participation by all farmers. However, (A4) implies that, when s_{min} depends on Θ, setting s to ensure participation by all farmers would not in general be optimal if subsidies are costly (i.e., if $\sigma>0$). Of course, if $\sigma=0$, then the second term in (A4) is equal to zero, implying that $s^* \geq s_{min}(\Theta_{max})$. In other words, if subsidies are not socially costly, the regulator would always want to set s sufficiently high to ensure participation by all farmers. Note, however, that in contrast to the case where s_{min} is independent of Θ here the absence of a background threat (i.e., p=0) does not imply that the optimal subsidy rate is one (implying full cost sharing).

Figure 1



Regulator
Don't offer Voluntary Program
Offer Voluntary Program
Legislature/Regulator
q
(1-q)
Impose Mandatory Controls
F: 2Cm(θ)
R: 2{B-ECm(θ)-T(1+σ)}
Don't Impose Mandatory Controls
F: 0
R: 0
Farmer
Participate
F: 2C*(θ)(1-s)
R: 2{B-EC*(θ θ∈Φ(s))(1+σs)}
Don't Participate
Legislature/Regulator
p
(1-p)
Impose Mandatory Controls
F: Cm(Θ)
R: B-ECm(Θ Θ∈Φ-1(s))-T(1+σ)
Don't Impose Mandatory Controls
F: 0
R: 0



p
1
Cm > C*
Cm = C* (1st best mandatory controls)
Firm Participates
s
½
1

Figure 2

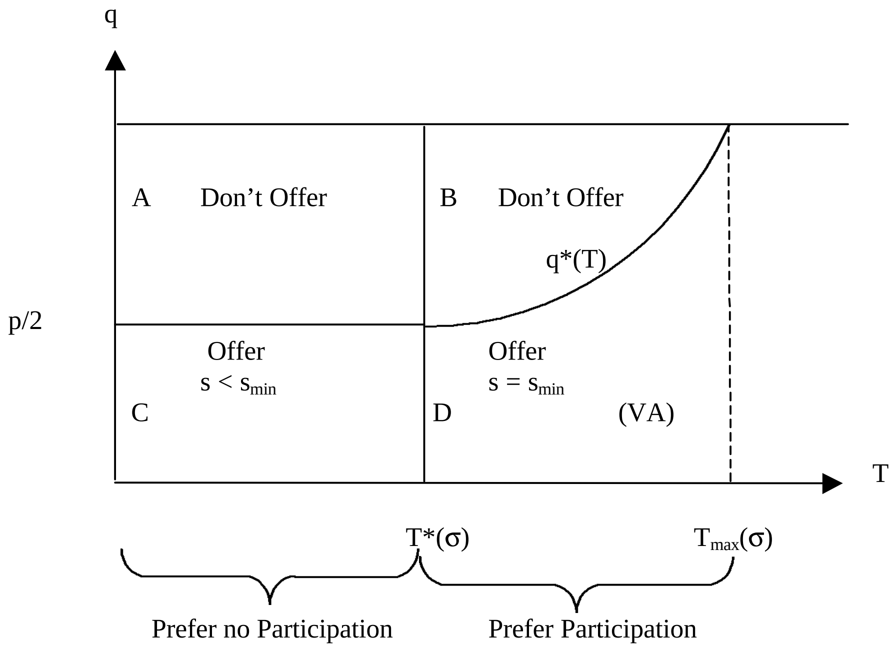

q
p/2
A
Don’t Offer
B
Don’t Offer
q*(T)
Offer
s < smin
Offer
s = smin
C
D
(VA)
T
T*(σ)
Tmax(σ)
Prefer no Participation
Prefer Participation

Figure 3

Figure 4

Farmer 2 \ Farmer 1	$a_1 = 0$	$a_1 = a_1^*$	$a_1 = a_1^s$
$a_2 = 0$	$pC(a_1^*)$ $pC(a_2^*)$	$C(a_1^*)(1-s) + C(a_1^*)$ $pC(a_2^*)$	$2C(a_1^s)(1-s)$ 0
$a_2 = a_2^*$	$pC(a_1^*)$ $C(a_2^*)(1-s) + C(a_2^*)$	$2C(a_1^*)(1-s)$ $2C(a_2^*)(1-s)$	$2C(a_1^s)(1-s)$ $2C(a_2^*)(1-s)$
$a_2 = a_2^s$	0 $2C(a_2^s)(1-s)$	$2C(a_1^*)(1-s)$ $2C(a_2^s)(1-s)$	$2C(a_1^s)(1-s)$ $2C(a_2^s)(1-s)$