The Use of Estimated Pollution Flows in Agricultural Pollution Control Policy: Implications for Abatement and Policy Instruments

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Flows of water pollutants from agricultural sources are, for all practical purposes, unobservable by direct monitoring. These flows can, however, be estimated using hydrological models. The analysis presented in this paper demonstrates that uncertainty on estimated flows is not neutral with respect to the optimal level and allocation of estimated abatement or with respect to the expected net benefits of alternative pollution control policy instruments. Policy implications are noted.

The primary basis for the nation's water pollution control programs is the Federal Water Pollution Control Act as amended in 1972. This legislation established a mandatory Federal program for point sources of water pollution but directed the states to develop nonpoint control programs [EPA, 1979b]. While the point source controls have produced significant accomplishments, state nonpoint control programs have provided negligible progress [GAO]. Yet, in many areas of the nation, including areas in the Northeast, nonpoint pollution is severe and represents the major obstacle to achieving the nation's water quality goals [EPA, 1984]. As a consequence, the implementation of effective nonpoint controls has become a major environmental policy issue.[1] Resulting initiatives will have particular significance for agriculture as the most pervasive generator of nonpoint source pollution [EPA, 1984].

The major problem in controlling agricultural nonpoint pollution is not a technological one. Research shows that changes in farm management practices can substantially reduce agricultural loadings [EPA, 1979a]. The significant obstacles are identifying management practices which are economical as well as effective (referred to as "Best Management Practices" (BMPs)), and inducing the adoption of these practices where they will be most beneficial [EPA, 1984]. Economic research contributing to the resolution of these problems has been significant [Alt and Heady; Boggess et al.; Miranowski et al.; EPA, 1978; Taylor and Frohberg; White and Partenheimer]. Several important economic questions remain, however.

One such question is the implications for identifying BMPs, targeting areas for control programs, and choices among implementation policies, of the substantial uncertainty regarding the magnitude of agricultural pollution flows. As with other nonpoint sources, pollution flows from farms into ground and surface waters cannot be monitored on a continuous and widespread basis with any reasonable degree of accuracy, or at reasonable cost, under existing economic and technical conditions. This circumstance would seem to limit severely the integration of efficiency considerations into the design of agricultural nonpoint abatement programs since critical factors influencing the costs and benefits of pollution control are the magnitude of total abatement and the allocation of this total among alternative polluters [Baumol and Oates].

There are, however, means by which to alleviate partially the monitoring problem. Hy-

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[1] At the time of this writing, the Senate Committee on the Environment and Public Works had recently prepared a bill (S. 2006) for the special purpose of amending the Clean Water Act to direct the states to develop and implement effective nonpoint control programs using either mandatory or voluntary strategies.

drological models have been developed for estimating agricultural nonpoint pollution flows by utilizing information on farm management practices, weather, soil characteristics, and other relevant factors and research to improve these models continues. It has been suggested that the efficiency of abatement programs can be improved by utilizing estimated pollution flows provided by these models as substitutes for actual flows [Anderson et al.; Griffin and Bromley]. This view appears to be well-received in economic research as models for estimating soil, nutrient, and pesticide losses have been widely incorporated into economic analyses of pollution abatement in agriculture. Perhaps the most important example is Taylor and Frohberg's work on the costs of alternative instruments, including taxes on estimated soil loss, in the Corn Belt. It must be emphasized, however, that in the current state-of-the-art, hydrological models serve to diminish but not to eliminate the uncertainty on agricultural nonpoint pollution. Consequently, estimates based upon observations of farm management practices and other relevant data do not offer a perfect substitute for accurate monitoring. Furthermore, it is unreasonable to expect that developments in this area will ever provide error-free predictions and, therefore, a perfect substitute for the true flows.

The purpose of this paper is to demonstrate that the uncertainty remaining after the adoption of nonpoint pollution estimation models is not neutral with respect to the efficient allocation of abatement levels among sources or the expected net benefits of alternative control policies. Implications for nonpoint abatement programs are noted. The analysis is based upon an adaptation and extension of Weitzman's and subsequent work to agricultural nonpoint pollution control.[2]

A Nonpoint Pollution Model

Fundamental implications of the uncertainty remaining on agricultural nonpoint pollution flows can be developed by considering a simple nonpoint pollution control model. Consider n polluting farms, a pollution regulator, and assume that there is only one pollutant. The pollution regulator is taken to be an expected net benefit maximizer. The issue to which this paper is addressed is introduced within this context by assuming that the regulator cannot observe the movement of the pollutant off the farms or the delivery of the pollutant to the receiving water body at reasonable cost by direct monitoring. To reduce the uncertainty about the flows, and thereby improve planning, the regulator uses estimates of field losses and delivery based upon observations of farm management practices and other relevant data. The choice of estimation model, while an issue of obvious interest and importance, is not considered in this paper. Instead, it is assumed that the regulator has already evaluated alternative hydrological models and adopted a specification consistent with some set of criteria. One consideration influencing this choice would be the farm production variables required as input data for alternative pollution estimation models and the costs of observing these data as well as the stochastic properties of alternative models. It is assumed below that the entire set of farm production variables is required and that this set can be observed without error at reasonable cost.

For the purposes of exposition, suppose that the pollutant is sediment and that the model chosen by the regulator for estimating sediment delivery consists of a soil loss model and a sediment transportation model. The regulator's soil loss model is written

$$\begin{aligned} R_i &= r_i e_i + \epsilon \\ e_i &= F_i(X_i) \qquad (1) \\ E[\epsilon] = 0,\ & E[\epsilon^2] = \sigma_\epsilon^2 \end{aligned}$$

where R_i is actual soil loss from farm i, e_i is an index of the erosivity of farm management practices on farm i, X_i is a vector of measurements on farm management practices (production variables) employed on farm i, and ϵ is a random error ($i = 1, 2, \ldots, n$).

It is emphasized that this specification is adopted for illustrative purposes. Ultimately, the relevant specification would depend, whether for sediment delivery control or other types of nonpoint pollutants, on the results of hydrological research and the use of that research by pollution regulation authorities. For the objectives of this analysis, the essential

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[2] Weitzman considers the effects of a public decision makers' uncertainty regarding the cost and benefit functions for a quantity on the comparative advantage of quotas over prices in regulation of the quantity. The quantity is assumed, however, to be readily observable. Weitzman's results regarding the neutrality of this uncertainty for the choice of instruments have been extended to pollution control issues in which monitoring is not problematic by Fishelson, Yohe, and Adar and Griffin, using frameworks which are essentially the same as Weitzman's.

feature of this specification is that it relates an unobservable emissions flow to observations of what is being done on the farm in a stochastic framework.[3] However, while this specification is primarily adopted for illustrative purposes, there is some "real world" appeal to it. To see this, consider the widely used Universal Soil Loss Equation (USLE) developed by Wishmeir and Smith. The form of the estimated USLE is $A = R \cdot K \cdot L \cdot S \cdot C \cdot P$ where A is estimated annual average gross erosion. The product of the first four variables is an estimate of annual average erosion on a continuously fallow but tilled field, given the soil, rainfall, and slope characteristics at the location. The product of the last two variables adjusts the previous quantity for the effects of crop management practices (e.g., crop rotations and tillage practices) and structural erosion control practices carried out on the field by the farmer. In effect, the product $C \cdot P$ serves as an index of the erosivity of farm management practices. In the specification of the erosion model above, the variable e_i may be thought of as an index such as $C \cdot P$ determined by observations on crop rotations, tillage practices, residue management practices and other variables required by the estimation model chosen by the regulator. These variables are the elements of the vector X_i. The parameter r_i may be thought of as analogous to the product $R \cdot K \cdot L \cdot S$, determined by observation of soil characteristics, weather factors, and other variables required by the estimation model chosen by the regulator.

The sediment transportation model adopted by the pollution regulator is written

$$(2) \qquad S = \sum_{i=1}^{n} s_i R_i + \gamma$$

$$E[\gamma] = 0,\ E[\gamma^2] \equiv \sigma_\gamma^2$$

where S is actual sediment delivery, s_i is the true expected sediment delivery ratio for farm i, and γ is a random disturbance ($i = 1, 2, \ldots, n$). Using (1), the sediment delivery model may be written

$$S = \sum_{i=1}^{n} c_i e_i + \lambda$$

$$c_i = s_i r_i \ (i = 1, 2).$$

$$(3) \qquad E[\lambda] = R\left[\sum_{i=1}^{n} s_i \epsilon + \gamma\right] = 0,$$

$$E[\lambda^2] = \mathrm{Var}\left[\sum_{i=1}^{n} s_i \epsilon + \gamma\right]$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} s_i s_j \sigma_\epsilon^2$$

$$+ 2\mathrm{Cov}(\epsilon, \gamma) \sum_{i=1}^{n} s_i + \sigma_\gamma^2$$

$$\equiv \sigma_\lambda^2.$$

The comments made above about the purpose and essential feature of the soil loss model specification apply to the specification of the sediment delivery model. There is, however, "real-world" appeal to this specification since sediment delivery ratios are widely used to relate erosion to sediment delivery.

From (3) it is evident that the uncertainty regarding sediment delivery will at least be due to random disturbances (ϵ and γ). However, it is reasonable to assume that the soil loss model parameters (r_i; $i = 1, 2, \ldots, n$), and the delivery ratios (s_i; $i = 1, 2, \ldots, n$) are unknown, thus adding to the uncertainty on delivery. Further, while the erosivity of farm management practices (e_i; $i = 1, 2, \ldots, n$) are, by assumption, readily observed once farmers have made management decisions, these quantities will generally be uncertain in a planning context. That is, when planning for pollution control, the regulator may be uncertain of the responses of farmers to some forms of intervention—e.g., participation in cost-sharing programs. This uncertainty arises as a result of imperfect information on abatement costs on farms. Consequently, in a planning context the uncertainty about sediment delivery will generally be further compounded by uncertainty of farm responses to policy because of uncertainty regarding the costs of abatement on farms.

To complete the model it is necessary to define costs and benefits. Following previous practice [Adar and Griffin; Fishelson; Weitzman; Yohe], the damage cost function, and the profit function introduced below, are specified as quadratic forms to facilitate the analysis. If the uncertainty in the problem is small this is not unreasonable; for then a second-order Taylor series expansion provides a reasonable approximation of the true functions about the optimum [Samuelson]. The sediment damage cost function is written

$$(4) \qquad D = d_0 S + d_1 S^2.$$

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[3] The form of (3) is fairly general in that it relates unobservable emissions to a vector of measurements of farm decisions in a stochastic framework. The purpose of the index e_i is to facilitate the analysis by simplifying notation.

It is further assumed, again following previous practice, that the regulator knows the true value of d_1, which is assumed positive, but is uncertain of the true value of the parameter d_0. These assumptions imply that the marginal damage cost is linear with a known (positive) slope but uncertain intercept. While these assumptions are simplistic, they are sufficient for the purposes of this analysis.

It is to be noted that (4) could be viewed alternatively as a representation of the regulator's own preferences rather than as a true damage cost function. This alternative view of (4) would seem appropriate if the regulator has insufficient information about economic damages to use damage costs to specify tradeoffs. It is also to be noted that there are limiting forms of (4) in which the marginal damage cost, in either view, approaches a vertical line at some level of sediment delivery. These limiting forms would imply either lexicographical preferences or extreme threshold effects. In the case of these limiting forms, the limiting form of the expected net benefit maximization problem facing the regulator is a problem of minimizing the expected costs of achieving a specified target level of total estimated sediment delivery.

Farm profits are expressed as a function of the erosivity of farm management practices. For farm i, the profit function is

$$\pi_i = a_ie_i + b_ie_i^2 \qquad (i = 1, 2, \ldots, n). \tag{5}$$

Optimal Estimated Pollution

Given probability distribution functions for the unknown parameters r_1, r_2, s_1, s_2, d_0, a_1, and a_2, and for the random disturbances ϵ and λ, the regulator can form an expectation of (6). This expectation is written

$$\begin{aligned} E[NB] = {} & (\hat{a}_1 - \hat{d}_0\hat{c}_1)e_1 \\ & + [b_1 - d_1(\hat{c}_1^2 + \sigma_1^2)]e_1^2 \\ & + (\hat{a}_2 - \hat{d}_0\hat{c}_2)e_2 \\ & + [b_2 - d_1(\hat{c}_2^2 + \sigma_2^2)]e_2^2 \\ & - 2d_1(\hat{c}_1\hat{c}_2 + \sigma_{12})e_1e_2 - d_1\sigma_\lambda^2 \end{aligned} \tag{7}$$

where $\hat{a}_1$, $\hat{a}_2$, $\hat{c}_1$, $\hat{c}_2$, and $\hat{d}_0$ are respectively the regulator's expectations of a_1, a_2, c_1, c_2, and d_0; and where $\mathrm{Var}(c_i) \equiv \sigma_i^2$ $(i = 1, 2)$ and $\mathrm{Cov}(c_1, c_2) \equiv \sigma_{12}$. It is assumed in this expression and below that the regulator's perceived distributions for the parameters c_1 and c_2 are independent of the perceived distributions of a_1, a_2, d_0, and λ. It is also assumed that the perceived distributions of a_1 and a_2 are independent of the distributions of d_0 and λ, which are in turn assumed to be independent. These assumptions are reasonable and do not detract from the analysis.

The values of the erosivity indexes (e_1 and e_2) which maximize (7) equate the expected profit of more erosive management to the expected damage cost of more erosive management at the margin for both farms. These optimal values are readily determined to be

$$e^*_i = \frac{d_1(\hat{c}_1\hat{c}_2 + \sigma_{12})(\hat{a}_j - \hat{d}_0\hat{c}_j) + (\hat{a}_i - \hat{d}_0\hat{c}_i)[b_j - d_1(\hat{c}_j^2 + \hat{\sigma}_j^2)]}{2[b_1 - d_1(\hat{c}_1^2 + \hat{\sigma}_1^2)][b_2 - d_1(\hat{c}_2^2 + \hat{\sigma}_2^2)] - 2d_1^2(\hat{c}_1\hat{c}_2 + \sigma_{12})^2} \tag{8}$$

$$(i, j = 1, 2;\ i \neq j).$$

As above, it is assumed that the regulator knows the true value of the parameter b_i, which is assumed negative, but is uncertain of the value of a_i $(i = 1, 2, \ldots, n)$. These assumptions imply linear marginal profits with known (negative) slopes but uncertain intercepts. Again, these assumptions are simplistic but sufficient for the purposes of this analysis.

Combining (3), (4), and (5) under the assumption that $n = 2$, the regulator's net benefit function is

$$\begin{aligned} NB = {} & (a_1 - d_0c_1 - 2c_1d_1\lambda)e_1 \\ & + (a_2 - d_0c_2 - 2c_2d_1\lambda)e_2 \\ & + (b_1 - d_1c_1^2)e_1^2 + (b_2 - d_1c_2^2) \\ & - 2d_1c_1c_2e_1e_2 - (d_1\lambda^2 + d_0\lambda). \end{aligned} \tag{6}$$

Assuming that the regulator constructs estimates of soil loss and sediment delivery using moments of the perceived distributions of parameters of the runoff and delivery models, this result implies the optimal estimated soil loss from farm i is $\hat{r}_ie^*_i$, where $\hat{r}_i$ is the regulator's expectation of $r_i (i = 1, 2)$. Optimal estimated sediment delivery is $\hat{c}_1e^*_1 + \hat{c}_2e^*_2$.

To consider how uncertainty on true erosion and sediment delivery affects the magnitude and allocation of the *ex ante* efficient estimated soil loss observe that:

$$\frac{de^*_i}{d\sigma_i^2} = \frac{d_1e^*_i[b_j - d_1(\hat{c}_j^2 + \hat{\sigma}_j^2)]}{D} \tag{9}$$

$$(10)\quad \frac{de^*_i}{d\sigma_j^2} = \frac{d_1[2e^*_i[b_i - d_1(\hat{c}_i^2 + \sigma_i^2)] - (\hat{a}_i - \hat{d}_0\hat{c}_i)]}{D}$$

$$(11)\quad \frac{d}{d\sigma_i^2}\left[\frac{e^*_i}{e^*_1 + e^*_2}\right] = \frac{-\,d_1e^*_i(\hat{a}_i - \hat{d}_0\hat{c}_i)}{(e^*_1 + e^*_2)^2}$$

where D is the denominator of (8).

In order for the second order conditions for a maximum to be satisfied it must be true that $D > 0$ and $[b_i - d_1(\hat{c}_i^2 + \sigma_i^2)] < 0$ $(i = 1, 2)$. Further, if $e^*_i > 0$ it must be true that $(\hat{a}_i - \hat{d}_0\hat{c}_i) > 0$ $(i = 1, 2)$. With these restrictions and the assumption that $d_1 > 0$ it follows that (9), (10), and (11) are each negative in sign. Together (9) and (10) imply that the greater the value of either σ_1^2 or σ_2^2, the lesser the optimal level of estimated soil loss and sediment delivery from both farms. Note that this implies that the optimal estimated levels of soil loss will be less than the estimated soil losses which maximize (6) when the random variables a_1, a_2, c_1, c_2, d_0, and λ are set to their expected values. The implication of (11) is that the greater is σ_i^2, the lesser the proportion of total estimated soil loss and sediment delivery from farm i $(i = 1, 2)$. Consequently, the greater the value of σ_i^2 the lesser the optimal estimated soil loss and sediment delivery from both farms and the lesser the proportion of the total estimated flows from farm i, all other things equal $(i = 1, 2)$.

To illustrate the importance of these results, suppose that the regulator ignores the uncertainty regarding the random variables a_1, a_2, c_1, c_2, d_0, and λ and proceeds as if their expectations were the true values. One consequence of this, given the assumptions of the model, would be to require too little estimated soil loss and sediment delivery abatement from both farms. A second may be misallocation of abatement among farms. For example, if it were the case that the expected marginal profit and sediment delivery functions were identical for both farms $(\hat{a}_1 = \hat{a}_2,\ b_1 = b_2,\ \text{and}\ \hat{c}_1 = \hat{c}_2)$, the certainty equivalent solution would distribute estimated control equally between the two farms. But if the uncertainty regarding the true runoff and delivery parameters is greater for the first farm than for the second $(\sigma_1^2 > \sigma_2^2)$, then estimated sediment delivery should be less from the first farm than from the second to maximize expected net benefits.

From this discussion it is evident that the uncertainty which remains on agricultural nonpoint pollution, after the adoption of models for estimating the unobservable flows, is not neutral with respect to either the total estimated level of expected net benefit maximizing abatement or the expected net benefit maximizing allocation of abatement among sources. The practical planning implications of this result will be discussed subsequently.

Choice of Instruments

The issue to which the analysis now proceeds is the implication of the uncertainty which remains on agricultural nonpoint pollution for the expected net benefits of alternative implementation policies. The purpose is not to evaluate exhaustively the broad range of alternative pollution control implementation strategies but is rather to demonstrate that the uncertainty which remains is not neutral with respect to the expected net benefits of alternative policy approaches. This is done by considering three alternative approaches which are particularly instructive. These alternatives are an estimated soil loss standard, a linear estimated soil loss tax, and restrictions on the choice of farm management practices.[4] These restrictions may also be thought of as land-use regulations. To simplify the analysis further, only one farm is considered.

Eliminating the second farm and maximizing expected net benefit with respect to e_1 identifies the *ex ante* efficient value of e_1 as

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[4] While each of these approaches has been proposed, the existing structure of point source control policy suggests that mandatory taxes and standards are not likely to be adopted to achieve nonpoint control. But this is not the issue being considered. Rather, the purpose is to demonstrate that the uncertainty on agricultural pollution has implications for the expected costs of alternative control strategies. It is, however, not unlikely, in the author's opinion, that mandatory technical restrictions will be adopted for nonpoint control if the Congress acts to require the states to achieve significant reductions. State nonpoint control programs which have emerged as a consequence of Section 208 of the Federal Water Pollution Control Act, as amended, have emphasized the voluntary approach which has long characterized soil conservation policy in the nation [EPA, 1979a; EPA, 1980]. At a time when state and Federal budgets are severely strained, farm subsidy policies in general are under attack, the effectiveness of voluntary soil conservation programs severely questioned, and the effectiveness of voluntary nonpoint control programs demonstrably negligible, it would seem unlikely that the states will uniformly pursue voluntary cost-sharing programs for nonpoint control if the Congress acts to require significant nonpoint abatement. Until the current deliberations on nonpoint control have taken their course and the states responded, the enforcement mechanisms for future nonpoint control remain uncertain. However, the appeal of the polluter-pays principle which has characterized industrial point source control and been manifested in technical restrictions policies would seem substantial under present circumstances.

$$(12)\qquad e^*_1 = \frac{-(\hat{a}_1 - \hat{d}_0\hat{c}_1)}{2[b_1 - d_1(c_1^2 + \sigma_1^2)]}.$$

This result is used to specify the optimal estimated soil loss standard: $\hat{r}_1e_1 \leqq \hat{r}e^*_1$. By imposing this standard the regulator insures that the estimated soil loss resulting from the farmer's selection of management practices ($\hat{r}_1e_1$) will not exceed the level of estimated soil loss the regulator believes to be optimal ($\hat{r}_1e^*_1$).

Farm profit with a linear tax on estimated soil loss is

$$(13)\qquad \pi = a_1e_1 + b_1e_1^2 - t\hat{r}_1e_1$$

where t is the tax rate on estimated soil loss. Maximizing profit with respect to e_1 identifies the farmer's optimum under the tax as

$$(14)\qquad e_1 = \frac{-(a_1 - t\hat{r}_1)}{2b_1}.$$

Substituting (14) into (6), absent the variable e_2, and maximizing the expected value of (6) with respect to the tax rate t identifies the expected net benefit maximizing tax rate as

$$(15)\qquad t^* = \frac{b_1\hat{c}_1\hat{d}_0 - \hat{a}_1d_1(\hat{c}_1^2 + \sigma_1^2)}{\hat{r}_1[b_1 - d_1(\hat{c}_1^2 + \sigma_1^2)]}.$$

Let $E[NB_1]$ denote the expected net benefit of the standard $\hat{r}_1e_1 \leqq \hat{r}_1e^*_1$ and let $E[NB_2]$ denote the expected net benefit under the tax $t = t^*$. Define Δ as $E[NB_1] - E[NB_2]$. This difference is the expected cost of choosing the optimal linear tax over the optimal standard. Assuming the range of a_1 to be such that the standard on estimated soil loss is always binding, this expected cost can be written

$$(16)\qquad \Delta = \frac{\sigma_a^2[b_1 + d_1(\hat{c}_1^2 + \sigma_1^2)]}{4b_1^2}$$

where $\sigma_a^2 = \mathrm{Var}(a_1)$.

If $\Delta > 0$ the optimal standard yields a greater expected net benefit than the optimal linear tax and will therefore be preferred on efficiency grounds. The reverse is true if $\Delta < 0$. If $\Delta = 0$ then neither policy is preferred to the other. The latter will be the case if $\sigma_a^2 = 0$. Consequently, a preference for one policy over the other, based on the expected net benefit criterion, will arise only if there is uncertainty regarding the marginal profit function. This result has been demonstrated previously [Weitzman; Fishelson; Yohe; and Adar and Griffin]. From this it follows that the uncertainty on agricultural nonpoint emissions, or the damage costs resulting from these emissions alone, will not imply an expected cost basis for choosing among these two policies.

Given that the marginal profit is uncertain ($\sigma_a^2 > 0$), the preferred policy will depend upon the sign of the numerator of (16). For the second order conditions for optimizing values of e^*_1 and t^* to be satisfied it must be true that $[b_1 - d_1(\hat{c}_1^2 + \sigma_1^2)] < 0$. This is satisfied by previous assumptions regarding the signs of b_1 and d_1. But, under these assumptions, the sign of (16) is ambiguous.

To consider the possibilities, suppose that the true value of the expected delivery parameter (c_1) is known so $\sigma_1^2 = 0$. That is, the pollution model is known up to an additive random variable (λ). The sign of (16) then depends upon the relative absolute values of b_1 and $d_1\hat{c}_1^2$. The former is the slope of the marginal profit function and the latter is the slope of the marginal damage cost function in terms of e_1. The tax policy is preferred to the standard under these circumstances if $|b_1| > d_1\hat{c}_1^2$. If $|b_1| < d_1\hat{c}_1^2$ the standard is preferred. Thorough discussions of the logic of these results may be found in several sources [Weitzman; Fishelson; Adar and Griffin]. Stated most succinctly, when the slope of the marginal profit is greater in absolute value than the slope of the marginal cost, the expected social cost from constraining the farm to e^*_1, when the true optimum is greater than or less than this quantity, exceeds the expected social cost of permitting the farm manager to respond to economic conditions better known to him than to the policy maker in the choice of e_1. The opposite is true when $|b_1| < d_1\hat{c}^2$.

Allowing for uncertainty in the value of c_1, the sign of (16) depends upon the relative magnitudes of $|b_1|$ and $d_1(\hat{c}_1^2 + \sigma_1^2)$. If $|b_1| < d_1\hat{c}_1^2$ the standard will be preferred to the tax regardless of the magnitude of σ_1^2. But, if $|b_1| > d_1\hat{c}_1^2$ the magnitude of σ_1^2 will determine the preferred policy. It is evident from this that the presence of uncertainty regarding the expected delivery parameter c_1 favors the estimated soil loss standard policy. The reason for this is that uncertainty regarding the value of c_1 implies uncertainty regarding the slope of the marginal damage cost in terms of the erosivity of farm management practices (e_1) and is accounted for in decision making by increasing the magnitude of the slope relative to its certainty equivalent.

Note that as d_1 (the slope of the sediment damage cost function) → ∞ the estimated soil loss standard will clearly be preferred to the estimated soil loss tax. This implies that an estimated emissions standard will be preferred to an estimated emissions tax when the regulator's preferences are of the limiting forms previously noted. Consequently, when the regulator wishes to minimize the expected cost of maintaining estimated sediment delivery below some value, an estimated soil loss standard is preferred to a tax on estimated soil loss.

Now, consider a policy of restricting the management practices selected by a farmer. Specifically, suppose that the regulator requires the farmer to choose from a set of practices determined to yield an estimated soil loss ($\hat{r}_1e_1$) less than or equal to the optimal estimated soil loss ($\hat{r}_1e^*_1$). These practices will be referred to as the set of BMPs designated by the regulator. If the set is exhaustive of all possible practices that will yield a value of $\hat{r}_1e_1 \leqq \hat{r}_1e^*_1$ it is obvious that the practice restrictions policy will be as efficient as the estimated emissions standards policy for the two policies are in fact the same policy. If, however, the set of permissible practices is not exhaustive of all possible practices that will yield $\hat{r}_1e_1 \leqq \hat{r}_1e^*_1$, the practice restrictions policy may not be as efficient as the estimated emissions standards policy and cannot be more efficient. The reason for this is simply that in this situation the management practices which achieve $\hat{r}_1e^*_1$ at least cost under some likely states of the world may not be included in the permissible set. From this it follows that the set of BMPs designated by the regulator ought to include all management practices which will permit the farmer to obtain a value of $\hat{r}_1e_1 \leqq \hat{r}_1e^*_1$ under likely states of the world. But, a policy of requiring the farmer to choose from this set of BMPs will be no more efficient than requiring the farmer to satisfy an estimated soil loss standard. Consequently, there is no expected cost basis for preferring a well-specified management practices restrictions policy to an estimated emissions standards policy under the assumption of this analysis. And this means that the comments made above when comparing a tax on estimated loss standards also apply to a comparison between the estimated soil loss tax and well-defined set of BMPs.

From these comments, it is evident that the uncertainty on agricultural nonpoint pollution remaining after the adoption of estimating models is not neutral with respect to the expected costs of alternative policies when abatement costs are uncertain. While this point has been demonstrated by comparing a select group of policies, it is generally applicable. Policy implications of this result are discussed below.

Summary and Conclusions

Whether the use of pollution estimation models for nonpoint pollution control planning is economically advantageous is a value of information problem. It would seem reasonable to expect the value of information to be significant as long as reasonably accurate estimation models can be developed. This, however, is not the issue with which this analysis is concerned. Reasonably accurate estimation models do not provide a perfect substitute for accurate monitoring. It has been demonstrated that the uncertainty which remains after the adoption of estimation models is not neutral with respect to the aggregate level of abatement, the allocation of abatement among sources, or choices among policy instruments. This discussion now turns to some practical implications of these results.

It is useful to preface this discussion by noting three key features that must be incorporated into state nonpoint control programs if they are to be effective and economical [EPA, 1984]. One is to identify the nonpoint sources which are responsible for delivering pollutants to significantly impacted water bodies. Another is to identify BMPs which will effectively and economically reduce nonpoint loadings to acceptable levels. The third is to select policy strategies that will secure the use of designated BMPs. Research and planning towards incorporating these features must clearly proceed under conditions of uncertainty on existing flows and responses of these flows to changes in management practices, the costs of changes in management practices, and the damage costs resulting from nonpoint loadings.

There are several implications of this analysis for targeting agricultural nonpoint sources and identifying agricultural BMPs to achieve water quality improvements in water bodies seriously impaired by these sources. The analysis implies that other things equal, farms and watersheds in which the uncertainty on agricultural loadings is greater should be called on to provide more estimated abatement than sources for which the uncertainty on loadings is less. The issue here has to do primarily with the perceived accuracy of prediction procedures in alternative situations. If, for example, the adopted prediction procedures are perceived to be more accurate in one farm setting than another or in one farming area than another, then, other things being equal, cost-benefit considerations indicate more estimated abatement from the more uncertain farms or farming areas. Such variations in the perceived accuracy of prediction methods are clearly to be expected in varying degree between farms within given areas and between farming areas. A variety of physical conditions and chemical processes influence the movement of nonpoint pollutants from farms to receiving waters. These factors can vary widely between locations and are better understood in some settings than in others [EPA, 1976]. This variation in understanding about the processes involved implies variations in the perceived accuracy of prediction methods. Practical considerations may limit the distinction between farms but the notion of targeting clearly calls for distinctions between sources by type of land-use and location [EPA, 1984]. The principal implication of this analysis for targeting is that variations in the perceived accuracy of prediction models for loadings must be accorded due consideration in determinations of areas in which control programs will be more economically beneficial.

The previous comments obviously imply that the uncertainty on nonpoint pollution should also have a role in designating BMPs for targeted sources. One important implication is that designated BMPs ought to provide for more estimated abatement than would be indicated by certainty equivalent constructs. This means that moments higher than expected loadings are relevant information when designating BMPs. Another implication is that BMPs designated for more uncertain sources, whether farms within watersheds or different watersheds, should provide for greater estimated abatement levels than BMPs designated for more certain sources, other things being equal. Again, practical considerations may constrain distinctions between farms within watersheds but for targeting to be successful, it is clear that distinctions between watersheds are necessary.

There are two principal implications of this analysis for choices among implementation policies. First, the analysis implies that the uncertainty on agricultural loadings will affect expected net benefits of alternative policy approaches and should therefore be considered when selecting appropriate policies. With regard to the specific policies considered, this analysis suggests that expected cost-benefit considerations favor a policy of setting nonpoint estimated emissions standards or a policy of requiring farmers to choose management practices from a well-defined set of BMPs, to a linear estimated nonpoint emissions tax policy. The second implication for policy choices follows from the first. The analysis of policy choices in the previous section indicated that there are several factors influencing the expected net benefits of alternative nonpoint abatement policies. These factors include the marginal costs and benefits of abatement and the uncertainty of abatement costs. These factors will vary from location to location and it follows that appropriate policies will vary from location to location and can be determined only after evaluating the relevant information for an area. An additional implication of this study is that variations in the uncertainty on nonpoint pollution between areas can be one basis for establishing different policies for different areas since this uncertainty can give rise to differences in the expected costs and benefits of alternative programs.

A further implication of this analysis is that the appropriate policy design for estimating control should evolve over time with improved information on control costs, benefits, and pollutant delivery. It is to be noted in this regard that since the expected net benefits of estimated control differ for different policy designs, the value of information on costs, benefits, and delivery depend on the policy used. This observation suggests that the value of research to improve information on delivery from farms as well as other aspects of the agricultural pollution control problem is a factor to be considered when formulating policy for managing estimated flows.

Before concluding this paper, some implications for the applied agricultural nonpoint research agenda should be noted. Little consideration has been given to the policy implications of uncertainty in the applied economic research on agricultural nonpoint source control to date [Kramer et al.]. This analysis indicates that uncertainty on farm profits and uncertainty on pollution flows from farms remaining after the adoption of pollution estimation models can have important implications for the design of pollution control programs for agriculture. Consequently, to provide policy makers with sound economic implications of programs designs it is essential that future applied investigations consider the role of uncertainty. To do so fully would require consideration of a number of issues beyond those incorporated into this analysis. Further issues this analysis points to directly or indirectly include the choice of estimation models, the costs of monitoring farm production and other program administration costs, and the implications of uncertainty on abatement costs faced by farmers.

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