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Internalizing Externalities of Phosphorus Discharges from Crop Production to Surface Water: Effluent Taxes vs. Uniform Reductions

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Some economists have argued that the "solution to pollution" is effluent taxes. Ideally, the effluent tax should be set at a level which equates marginal social (economic) costs of effluent reduction with marginal social (economic) benefits of such reduction. Because of the difficulty of measuring these costs and benefits, particularly the benefits, in recent years economists have suggested an alternate approach. This approach requires that a socially acceptable standard of environmental (water) quality be set. Effluent taxes would then be used to achieve this standard. It has been argued that effluent taxes would achieve this standard at lower economic (social) cost than would policies such as uniform treatment or uniform reduction in effluent discharge by each discharger (Kneese; Kneese and Bower; Baumol and Oates; Baumol; Freeman, Haveman and Kneese). Horner has presented a concise review of the case for effluent taxes. Few economists have disagreed with this argument.

The argument that an effluent tax is preferable to a policy of uniform treatment on economic grounds is depicted in Figure 1 for the case of phosphorus discharges to surface water. For convenience, linear marginal costs and benefits have been shown. The levels of phosphorus discharge and water quality before the imposition of either policy are at X. Zero discharge of phosphorus (or zero marginal benefit) is represented by H. Since we argue that taxes are less costly than a policy of uniform reduction in discharge, the marginal social cost of the effluent tax policy will be lower at any level of water quality than will be the marginal social cost of the uniform reduction policy. If marginal social

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costs and benefits were equated, water quality would be higher (T) for the tax policy than for the uniform reduction policy (R). For a given level of water quality such as R, the cost with the tax (XCR) would be less than the cost with uniform reduction (XAR).

The net social benefits would be greater with the effluent tax than with the uniform reduction policy. In figure 1, if R were chosen as the desired water quality, with the tax policy social benefits would be XEAR, social costs would be XCR and net social benefits would be XEAC. With the uniform reduction policy, net benefits would be XEA; therefore the net benefits with the tax policy would be greater by XAC.

Only social costs and benefits are shown in Figure 1. Effluent taxes paid by dischargers are a transfer payment and not included in social costs of the effluent tax policy. Little attention has been given in the literature to the costs to dischargers of a tax policy compared to a uniform reduction policy. Depending on the effluent tax required to achieve a level of water quality such as R in figure 1, the cost to dischargers of the tax policy could be greater than the cost of the uniform reduction policy. In this example, the tax required per unit of discharge would be RC [1/] and the total tax would be RC times RH, the remaining discharge after reduction.

There have been few empirical studies of effluent taxes vs. uniform reduction as alternatives to achieve a given level of water quality. A recent study by Horner of nitrate nitrogen in irrigation return flow found that a 2 ppm. NO_3 - N standard could be achieved at lower cost with a charge (tax) policy than with a treatment policy. In this case, treatment was done in one large plant and consequently it is not clear that Horner's study was making the comparison

1/ At a tax level of RC, at R the discharger would be indifferent to paying the tax or reducing discharge. At reductions in discharge less than R, the discharger would find it less costly to reduce discharge and beyond R he would find it less costly to pay the tax than to reduce discharge.

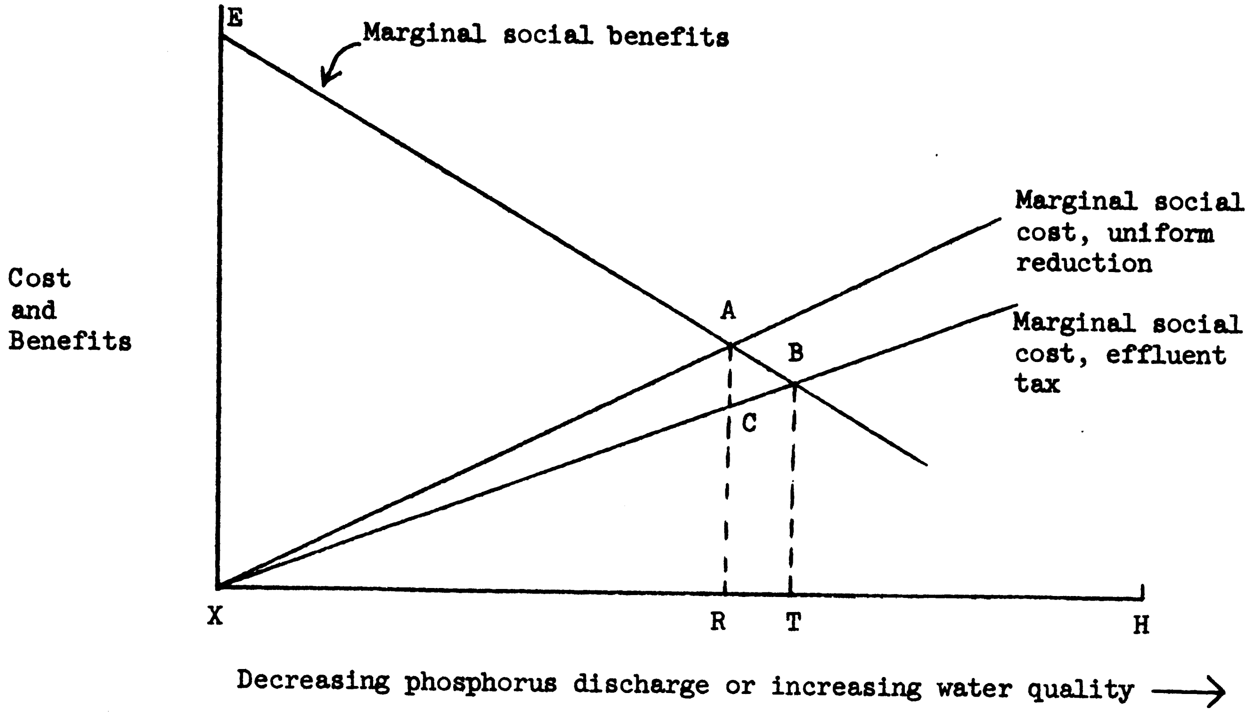

Figure 1. Social (or economic) benefits and costs from decreasing phosphorus discharge by policies of effluent taxes or uniform reductions.

Table 1. Costs of reducing soluble phosphorus discharge to Cayuga Lake from crop production in the Fall Creek Watershed with uniform reduction and effluent tax policies

Percent reduction in phosphorus discharge	Lbs. of soluble phosphorus discharged a/	Economic Costs: Uniform reduction policy b/	Economic Costs: Effluent tax policy	Tax revenue	Total cost to farmers of tax policy
10	21,695.4	$ 37,177	$ 32,065	$ 464,065	$ 496,130
20	19,284.8	132,748	126,556	980,246	1,106,802
30	16,874.2	268,697	259,037	954,742	1,213,779
40	14,463.6	416,056	406,677	984,393	1,391,070
50	12,053.0	591,906	590,193	1,019,684	1,609,877
60	9,642.4	844,945	842,126	1,440,092	2,282,218

a/ The soluble phosphorus discharged before application of either policy was estimated to be 24,106 lbs.

b/ With the uniform reduction policy, economic costs are also the total costs to farmers.

of effluent taxes with uniform reduction by all dischargers that has been discussed in the literature. Therefore Horner's work may be only a partial empirical test of the theoretical conclusion that effluent taxes are more efficient than uniform reduction in achieving a given level of water quality.

Research conducted on phosphorus in recent years lends itself to further empirical work on the issue (Casler and Jacobs). Companion research strongly suggests that reduction in soluble phosphorus inputs would decrease algal production in lakes in temperate latitudes (Oglesby and Schaffner). Presumably there are social benefits of reductions in phosphorus discharges to such lakes, at least over some range of reduction.

The purpose of this paper is to compare the social costs of achieving given levels of reduction in phosphorus discharge from crop production by using either effluent taxes or uniform reduction and to compare the cost to farmers of achieving these same reductions under the two policies.

Case Study: The Fall Creek Watershed

This paper deals with a study which estimated the costs of reducing soluble phosphorus discharges to surface water from crop production in the Fall Creek watershed. The analysis allows one to compare an effluent tax policy with a uniform reduction policy. Fall Creek is a major tributary of Cayuga Lake, one of the largest of the Finger Lakes of central New York. The watershed covers 125 square miles and contains 130 dairy farms. The major crops grown are corn grain, corn silage, hay or hay crop silage, oats and wheat.

Empirical Model

The cost of reducing phosphorus discharges due to surface runoff and soil erosion was estimated with a linear programming model of farming in the Fall Creek watershed. Production activities consisted of dairy cows, raised and purchased replacements, alternative crop rotations for each soil type, commercial fertilizer, purchased grain and protein supplement and hired labor. Soil erosion losses for each rotation on each of 19 combinations of soil type and slope were estimated using the universal soil loss equation (Wischmeier and Smith). Phosphorus losses were estimated from soil losses by using the phosphorus content of the topsoil and an enrichment ratio representing the increased content of phosphorus in the eroded material (Casler and Jacobs). Since all the soil eroded from fields does not reach the stream, a delivery ratio was needed. The estimated delivery ratio for the watershed was .1 (EPA, 1973). Since soluble phosphorus, rather than total phosphorus, is believed to control algal production, an estimate was made of the proportion of the total phosphorus discharged which was soluble.

A profit maximizing initial solution of the LP model was computed with no restrictions on phosphorus discharges. This solution was constrained to closely resemble the farm production activities found in the watershed in a 1973 survey. To simulate uniform percentage reductions in phosphorus discharges from each farm, the LP model was divided into three subwatersheds. Each of these three subwatersheds was treated as a farm. Phosphorus discharges in each subwatershed were restricted by increments of 10 percent of the estimated discharge in each subwatershed in the initial solution. To simulate the imposition of an effluent tax, a single restriction on phosphorus discharge from the entire watershed was introduced, also in increments of 10 percent. The shadow prices on each of these restrictions are the effluent taxes required to achieve the given percentage reduction in phosphorus discharge.[1/]

1/ An interesting point related to the effluent tax policy is that the tax (equivalent to the shadow price) cannot be directly applied in the linear programming model to achieve exactly the same discharge as the single restriction on phosphorus discharges in the entire watershed. That solution was at

Under either policy, the LP model computed the least cost rearrangement of production activities to comply with the policy. For the uniform reduction policy, rearrangement could occur only within each subwatershed while under the tax policy, the rearrangement could occur within the entire watershed. The latter case should be less costly because the reduction in phosphorus discharge can occur in the least cost place within the entire watershed.

The reduction in phosphorus discharge was achieved by substituting cropping activities with lower phosphorus discharge (rotations with more hay and less corn) for those with higher phosphorus discharges. Because corn produces more feed energy per acre than hay crops, shifting rotations reduces the amount of energy produced in the watershed. It was profitable to hold cow numbers and milk production in the watershed at the levels in the initial solution. The cost of complying with either policy was the cost of purchasing additional feed from outside the watershed, less the reduction in production costs if hay rather than corn was grown. In the case of the effluent tax, the farmers would also be required to pay the tax on the amount of phosphorus discharge remaining after any reduction in phosphorus discharge.

Empirical Results

The costs of achieving phosphorus discharge reductions of 10 to 60 percent from crop production in the watershed are shown in table 1. Three sets of costs are shown: (1) economic costs of achieving reduction in phosphorus discharge under each policy, (2) tax revenue collected, which is a cost to farmers

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one of the corner points of the phosphorus restriction in the LP model. When the restriction is removed and the effluent tax applied, the corner point no longer exists and solution moves to the next corner point which will have a higher or lower phosphorus discharge, depending on whether the tax imposed is rounded down or up from the shadow price obtained from the solutions in which restrictions were applied.

and, (3) total cost to farmers of obtaining each phosphorus reduction with either policy.

The economic cost is the cost to society of the feed production forgone within the watershed in order to reduce phosphorus discharge to Cayuga Lake. In terms of economic cost, the effluent tax policy allows each level of phosphorus discharge reduction to be achieved more efficiently than does the uniform reduction policy, i.e., a smaller decrease in feed production in the watershed is required to achieve a given level of phosphorus discharge.

The results of the study are shown graphically in figure 2, which is analogous to the theoretical Figure 1, except that marginal benefits are not shown because no attempt was made to estimate benefits in our study. The graph shows that the economic cost of achieving any level of phosphorus reduction is lower with the effluent tax than with uniform reduction in each watershed. For example, at 40% reduction, the economic cost is XAR for the uniform reduction policy but XCR for the effluent tax policy.

While the economic cost of reducing phosphorus discharge is less with the effluent tax policy, the total cost to farmers is much greater for the tax policy than for the uniform reduction policy (Table 1). In figure 2, the cost to farmers of the tax policy is XCR plus RCGH. Of course, the taxing body receives revenue (RCGH) equal to the tax paid by farmers.

Discussion

Most theoretical discussions have failed to mention that the total cost to dischargers may be greater under an effluent tax policy than under a uniform reduction policy, even though the economic cost is lower (Baumol). While this information has been reported with the results of some empirical studies, the tendency has been to either omit such data or obscurely refer to it. For example, Johnson, in reporting the results of the study of the Delaware estuary,

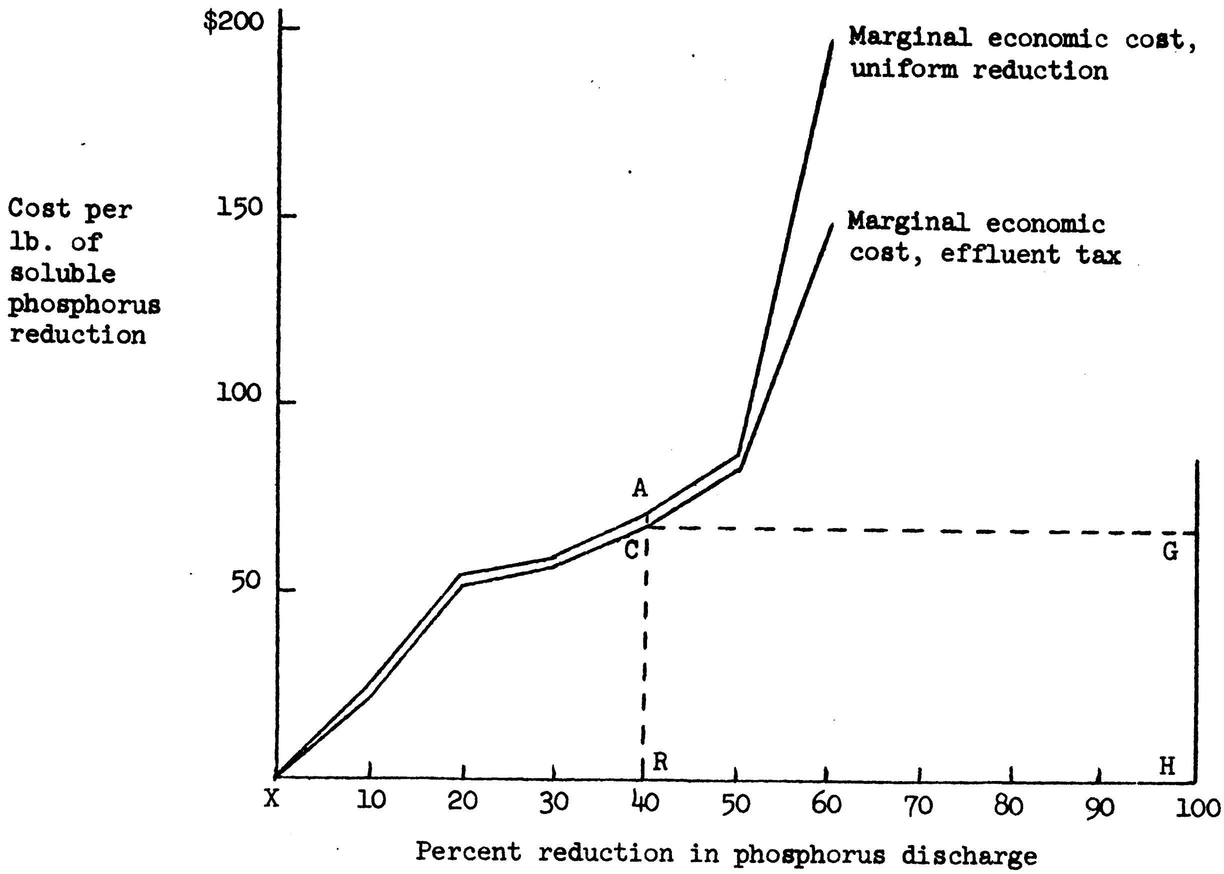

Figure 2. Economic costs of decreasing phosphorus discharge from crop production in the Fall Creek watershed by policies of effluent tax or uniform reduction.

Table 2. Costs to farmers of reducing soluble phosphorus discharge from cropland in the Fall Creek Watershed to Cayuga Lake

Percent reduction in phosphorus discharge	Soluble phosphorus discharge (lbs.)	Cost per farm: Uniform reduction	Cost per farm: Effluent tax	Percent of net income: Uniform reduction	Percent of net income: Effluent tax
10	21,695.4	$ 286	$ 3,816	2	32
20	19,284.8	1,021	8,513	9	71
30	16,874.2	2,067	9,337	17	78
40	14,463.6	3,200	10,701	27	89
50	12,053.0	4,553	12,384	38	103
60	9,642.4	6,500	17,556	54	146

states in the text that effluent taxes were included in his costs but his tables are labeled "economic costs". Kneese and Bower, in reporting the results of the same study made it clear that Johnson's costs were economic costs and pointed out that dischargers would also pay the tax, thus making their total costs nearly equal to the cost for uniform treatment. However, in a later publication reporting the same study, Freeman, Haveman, and Kneese failed to mention that dischargers would bear the tax in addition to the economic costs of reducing effluent.

While most of the theoretical discussions have ignored the fact that total costs to dischargers may be higher with a tax than with either a uniform reduction or uniform treatment policy, and empirical studies have not stressed this point, an example used by Freeman, Haveman and Kneese clearly illustrates that this may occur. In their example while an effluent charge would cost $26 compared to $45 for uniform reduction and $56 for uniform treatment, the tax would be $72, making the total cost of the effluent charge policy to the dischargers $96 or roughly double the cost of either of the other policies. While the authors correctly point out that the tax revenue could be used for improving the quality of the stream and that it is a transfer payment, they fail to discuss the fact that the higher cost of the tax policy to dischargers has implications for political acceptance of the charge policy.

In our case the effluent tax that would be required to reduce phosphorus losses, when added to the reduction in income, makes the total cost to farmers of the tax policy substantially (2.7 to 13.3 times) higher than the cost of a uniform reduction policy. While the economic cost of the tax policy is lower and society would have the tax revenue, the farmers involved would be unlikely to prefer a tax policy to a uniform reduction policy if they knew the probable costs of each policy to them.

A Tax-Subsidy Proposal

In our case, policy makers might consider using the effluent tax revenue to provide an incentive to farmers to cooperate with the effluent tax policy which has lower economic costs than the uniform reduction policy.1/, 2/ While the effluent tax policy could be imposed on farmers without their consent, the high cost to farmers suggests that they would prefer the uniform reduction policy if forced to choose between the two. Their preference is illustrated rather dramatically in Table 2. The reduction in net income (defined as labor and management income plus return to equity capital and estimated to be $12,000 per farm) is much larger with the effluent tax policy than with the uniform reduction policy. Reductions in discharge as small as 20 or 30 percent take from farmers about 75% of net income.

If repayment of part of the tax to farmers were to be considered one challenge would be to find a way to make such a payment without negating the effect of the tax in reducing phosphorus discharge to the lake.

1/ In our case, the difference in economic costs between the two policies is small enough so that no great waste of resources would be incurred if the uniform reduction policy were chosen rather than the tax policy. If we had been considering all 130 farms rather than three watersheds (pseudo farms) the difference in economic costs between the two policies probably would have been greater.

2/ The reader is probably aware that neither uniform reduction or effluent taxes could be directly applied in this non-point source situation in the same way that they could be in the situation of point sources where effluent can more easily be measured. Our major objective is to point out that an effluent tax policy may cost dischargers more than a uniform reduction policy even though economic costs are less. In this non-point situation, either policy would need to be applied in a proxy manner. Changes in cropping programs would be imposed and effluent taxes collected on the basis of estimated phosphorus discharges from various crops, slopes and soil types rather than on the basis of actual measurement of discharges. The uniform reduction policy may be administratively less costly but we have not studied this issue.

One possibility would be to offer to pay farmers a subsidy or incentive for each pound of soluble phosphorus reduction for the tax policy but not for the uniform reduction policy. This tax could be set to make the net cost to farmers of the tax policy higher than, equal to or lower than the cost of the uniform reduction policy. In our case if the subsidy was set to make the cost to farmers (as a group) of the tax policy equal to the cost of the uniform reduction policy there would be incentive to reduce phosphorus discharges far below levels which would be achieved by a tax alone. In addition, as discharges were reduced, subsidies paid would soon exceed taxes collected unless a limit was placed on total subsidies.

The addition of a subsidy to the tax policy would in effect lower the marginal cost to farmers of achieving reductions in phosphorus discharge. Appropriate combinations of taxes and subsidies could be found to achieve the desired reduction in phosphorus discharge. However, such combinations might not make the cost to farmers of the tax policy as low as the cost of the uniform reduction policy. It is not our intent in this paper to find the appropriate combination of tax and subsidy but only to suggest that such a policy might be considered.

Summary

Despite the rather widespread advocacy of effluent taxes by economists as the "solution to pollution", few have pointed out that the cost to dischargers of such a policy may be greater than the cost of a uniform reduction or uniform treatment policy. Research reported here shows that in the case of soluble phosphorus discharge from farmland, the tax policy may be far more costly to farmers. Perhaps a combination of effluent taxes and subsidies for reduction of discharge could be used to retain the benefits to society of lower economic costs of the tax policy and still not place an excessive cost on dischargers.

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