J. ENVIRONMENTAL SYSTEMS, Vol. 24(2) 151-167, 1995-96

MARKET INCENTIVES TO REDUCE NONPOINT SOURCE AGRICULTURAL NUTRIENT POLLUTION: A THEORETICAL AND IMPLEMENTATIONAL DISCUSSION

MARC E. NORMAN

JOHN D. KEENAN

University of Pennsylvania, Philadelphia

ABSTRACT

This article provides a theoretical and implementational discussion of several potential market-based mechanisms to reduce nonpoint source agricultural nutrient pollution, including an excess nutrient tax; off-site animal waste disposal subsidy; animal waste transport subsidy; compost subsidy; and nutrient permit trading system. Market incentives have theoretical appeal in that, if set at the proper level, they compel polluters to reduce pollution generation to the socially efficient level automatically. However, each market-based mechanism has associated implementational factors which must be overcome. The implementation discussion highlights the basic information, monitoring, enforcement, and political requirements concerning each of the policies. In addition, market inefficiencies may reduce the practical effectiveness of market-based incentives. In cases where informational and other inefficiencies are high, alternative approaches (such as market surveys and nutrient management education) aimed at reducing those inefficiencies may be required.

1.0 INTRODUCTION

Nutrients such as nitrogen and phosphorus are essential for agricultural crop growth. In excess amounts, however, they can cause water pollution problems such as eutrophication. The EPA estimates that nutrients are the most widespread

doi: 10.2190/0APH-V62F-JEUA-GT6X
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cause of lake pollution and the second most widespread *cause* of river pollution in the United States [1]. Agriculture is the most widespread *source* of both lake and river pollution. Agricultural nutrient pollution, due to its nonpoint nature, is difficult to monitor and control. The Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 constitute the most extensive federal legislation to deal directly with nonpoint source water pollution, requiring coastal states to develop federally approved nonpoint source programs. As part of those programs, each state must develop a nutrient management plan.

One of the principal means by which states may reduce nonpoint nutrient pollution is through the application of market incentives. Market incentives have theoretical appeal in that, if set at the proper level, they compel polluters to reduce pollution generation to the socially efficient level automatically. This article provides a discussion of the theory and implementational factors of several market-based incentive schemes to reduce nutrient pollution, including an excess nutrient tax; off-site animal waste disposal subsidy; animal waste transport subsidy; compost subsidy; and nutrient permit trading system. The implementation discussion highlights the basic information, monitoring, and enforcement requirements to implement each of the scenarios. Political factors are also discussed.

2.0 RELATED RESEARCH

The broadest study concerning agricultural nonpoint source pollution has been the Rural Clean Water Program (RCWP), a ten-year experimental effort sponsored by the federal government in 1980 to address agricultural nonpoint source pollution problems in watersheds across the country. The objectives of the RCWP were to:

> 1) achieve improved water quality in the approved project area in the most cost-effective manner possible in keeping with the provision of adequate supplies of food, fiber, and a quality environment; 2) assist agricultural landowners and operators to reduce agricultural NPS water pollutants and to improve water quality in rural areas to meet water quality standards or water quality goals; and 3) develop and test programs, policies, and procedures for the control of agricultural NPS pollution [2].

The RCWP funded twenty-one experimental watershed projects across the country. It was administered by the USDA Agricultural Stabilization and Conservation Service in consultation with USEPA. According to an RCWP evaluation report, the project provided the following contributions:

> The Rural Clean Water Program is one of the few national programs that has combined land treatment and water quality monitoring in a continuous feedback loop to document NPS control effectiveness. Water quality monitoring results have also been used to adjust and refine land treatment practices designed to control agricultural NPS pollution. . . .

> Many of the RCWP projects have made significant contributions to the body of knowledge regarding nonpoint source pollution, NPS control technology, [Best Management Practice] effectiveness, and the effectiveness of voluntary cost-share programs aimed at assisting producers in reducing agricultural NPS pollution. . . .
> The program achieved extensive adoption of BMPs in critical areas (and often beyond project boundaries) and provided valuable insight into the effectiveness of these practices in improving water quality. Possibly the most important contribution made by the RCWP is the advancement of our understanding of how to plan, implement, manage, and monitor voluntary agricultural NPS pollution control efforts [2].

Further research concerning nonpoint source pollution control strategies include Coffey et al. [3], who discuss the elements of a model program for nonpoint source pollution control based on the RCWP experience, and Young et al. [4], who developed the AGNPS model to evaluate nonpoint source pollution in agricultural watersheds. The model is designed to analyze nonpoint source pollution and to prioritize water quality problems in rural areas.

An expanding literature exists concerning theoretical aspects of nonpoint source pollution control. Griffin and Bromley provide a theoretical development of agricultural runoff as a nonpoint externality [5]. Shortle and Dunn examine the relative expected efficiency of four general strategies for achieving agricultural nonpoint pollution abatement [6]. Emphasis is placed on the implications of differential information about the costs of changes in farm management practices, the impracticality of direct monitoring, and the stochastic nature of nonpoint pollution. The possibility of using hydrological analyses to reduce the uncertainty about the magnitude of nonpoint loadings is incorporated into the analysis. The principal result is that appropriately specified management practice incentives should generally outperform estimated runoff standards, estimated runoff incentives, and management practice standards for reducing agricultural nonpoint pollution.

Segerson provides a theoretical discussion of the effects of uncertainty on incentives for nonpoint pollution control. According to Segerson:

> In dispersed or nonpoint pollution problems, monitoring of individual polluting actions is difficult and those actions cannot generally be inferred from observed ambient pollution because (i) ambient pollution levels have a random distribution that is contingent on the level of abatement undertaken and/or (ii) the actions of several polluters contribute to the ambient levels and only combined effects are observable [7].

Her paper describes a general incentive scheme for controlling nonpoint pollution. Rewards for environmental quality above a given standard are combined with penalties for substandard quality. The mechanism is discussed in the context of both a single suspected polluter and multiple suspected polluters where free riding must be avoided.

Cabe and Herriges study the regulation of nonpoint source pollution under imperfect and asymmetric information [8]. Their paper develops a Bayesian framework for discussing the role of information in the design of nonpoint source pollution control mechanisms. An ambient concentration tax is examined, allowing for spatial transport among multiple zones. According to the authors, imposition of the tax requires costly measurement of concentrations in selected zones, and the selection of zones for measurement must be undertaken without perfect information regarding several parameters of the problem. Potentially crucial information issues discussed in the paper include the impact of asymmetric priors regarding fate and transport, the cost of measuring ambient concentration, and the optimal acquisition of information regarding fate and transport.

Several studies have looked at the decision-making processes of farmers concerning adoption of best management practices for nutrient management, and how those processes are affected by various government policies. McSweeny and Kramer, for example, developed a model to study farmer decision making regarding choice of best management practices under a government program of cross-compliance, and within a risk framework [9]. Southgate et al. developed a linear programming model of a dairy farm to estimate the minimum subsidy rate necessary to induce dairy farmers to implement less-polluting manure management systems [10]. Finally, Just and Antle developed a conceptual framework to analyze the interactions between agricultural and environmental policies and pollution [11].

3.0 THEORY

A theoretical representation of each of the policy options is provided below.

3.1 Excess Nutrient Taxes

One potential policy is to place a tax on any nutrient which is above the recommended value for a given farm. The purpose of this is to force the farmer to internalize the environmental social costs associated with the excess nutrients. According to Figure 1, P* is the cost of removing a unit of nutrient from the farm. For purposes of simplicity, it is assumed to be a constant value. MC is the marginal cost curve for a given farmer for retaining excess nutrients on the farm. The cost curve is increasing to suggest that excess nutrients can have deleterious effects on the farmer's crops. All else being equal, the farmer will maintain excess nutrients on the farm up to the point where the marginal cost of the nutrients equals the cost of removal. This occurs at q*.

MCS represents the true social cost of the excess nutrients. The difference between MCS and MC is that MCS includes the external environmental costs

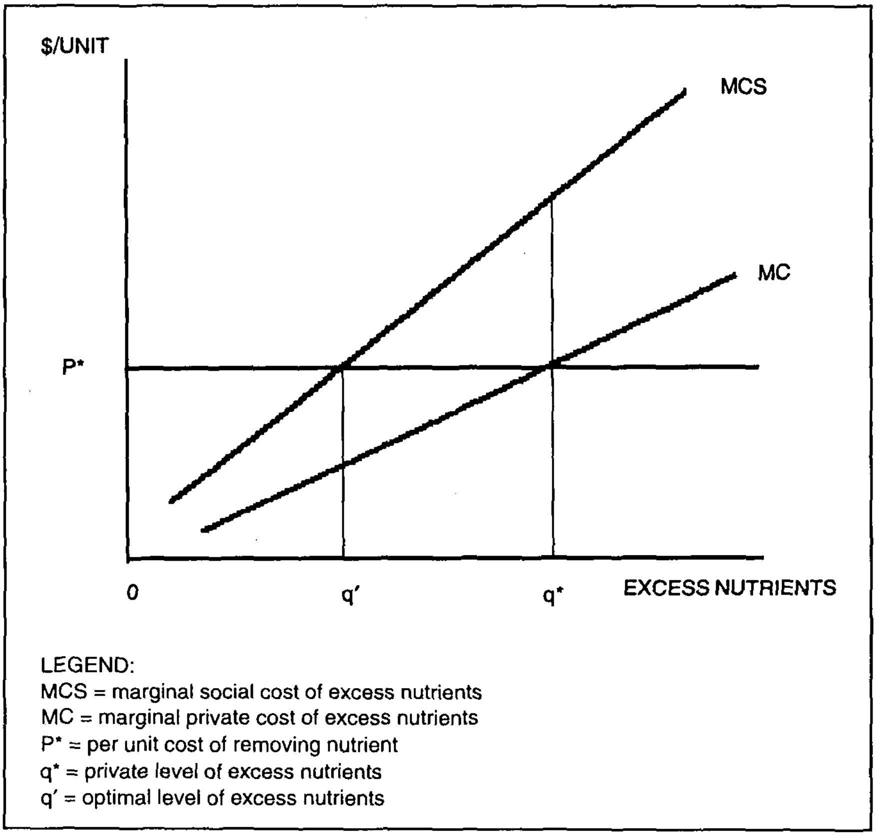


Figure 1. Excess nutrient tax.

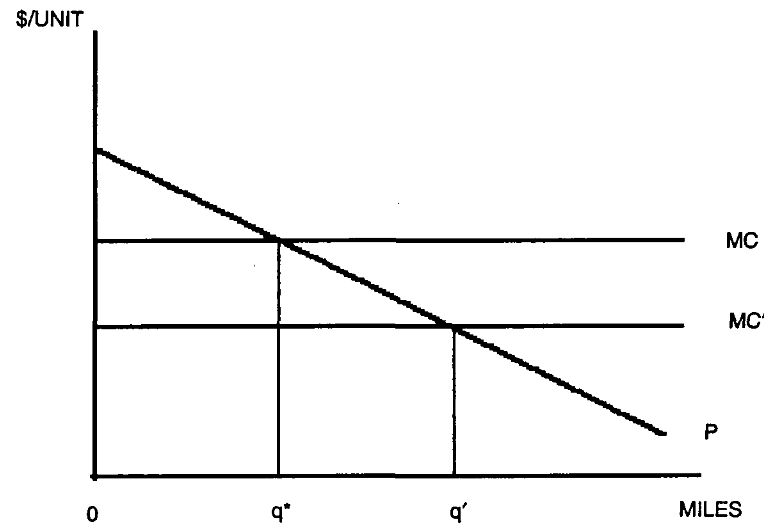
which the farmer does not take into account in his private calculations. The optimal social level of excess nutrients is the point where the marginal social cost equals the cost of removal. This occurs at q′.

The purpose of the tax is to reduce the farmer's amount of excess nutrients from q* to q′. This is achieved by placing a tax equal to the difference between MCS and MC at the point q′. This tax shifts the MC curve upward so that it intersects P* at the socially optimal point.

3.2 Waste Transport Subsidy

Subsidies are, in effect, the reverse side of the coin from taxes. In this case, rather than forcing the internalization of external costs, the government provides some sort of payment in order to encourage practices or technologies which reduce pollution. Since transportation cost is an integral factor in transferring wastes from surplus to deficit regions, waste transport subsidies are an obvious mechanism to encourage such transfers.

In Figure 2, P represents the per-mile price that farmers are willing to pay to ship a ton of waste. The decreasing nature of this curve reflects the fact that, assuming a constant per-ton willingness to pay for waste transport, the customer's willingness to pay for per-ton-mile transportation costs decreases with increased shipping distance. MC is the marginal cost of shipping the waste. For purposes of simplicity, this value is considered to be constant. That is, there are no economies of scale. According to this scenario, waste will be shipped up to distances equal to q*. No waste will be shipped beyond that point, since after q* the marginal transportation cost exceeds the customers' willingness to pay for an extra mile shipped.



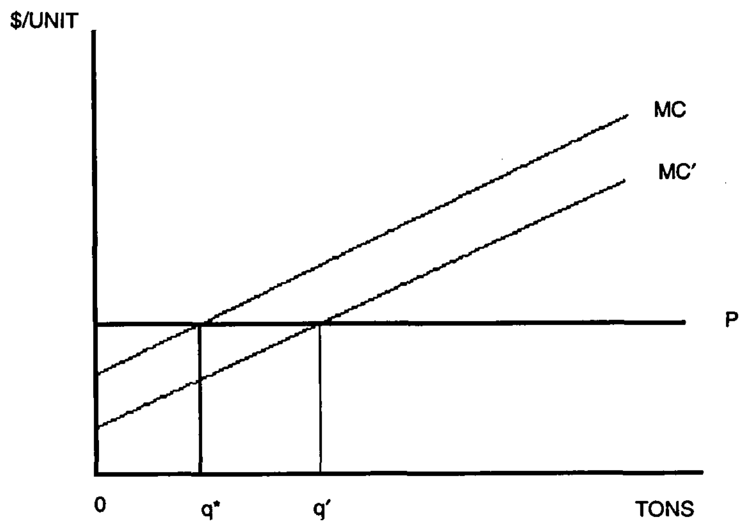
LEGEND:
MC = marginal private cost of shipping waste
MC′ = marginal shipping cost with subsidy
D = demand curve for waste transport
q* = maximum private shipping distance
q′ = maximum shipping distance with subsidy

Figure 2. Waste transport subsidy.

Providing a per-ton-mile transport subsidy to shippers effectively reduces the cost of shipping. Accordingly, with a subsidy imposed, the marginal transport cost shifts from MC to MC′. A new equilibrium point is reached at q′. At this point, since the per-ton-mile price of waste transport has been reduced from the original equilibrium point, customers are now willing to ship the waste over greater distances.

3.3 Off-Site Disposal Subsidy

Closely related to the waste transport subsidy is the off-site disposal subsidy. In this case, however, instead of providing shippers a per-ton-mile subsidy, the government provides a flat per-ton subsidy to farmers who have their waste shipped off-site. This scenario is shown graphically in Figure 3. Here, the



LEGEND:
MC = marginal private shipping cost
MC′ = marginal shipping cost with subsidy
P = marginal willingness to pay for waste
q* = private quantity of waste shipped
q′ = waste shipment quantity with subsidy

Figure 3. Off-site disposal subsidy.

marginal shipping cost per ton (MC) is an increasing function due to the fact that as more waste is shipped, it must be transported over longer distances. Customers are considered price takers so that the marginal willingness to pay (P) is constant. (While this is probably not the case in reality, since those who live farther away from manure sources are probably willing to pay somewhat more to have the waste shipped to them, it is a reasonable assumption for purposes of illustration.) The equilibrium amount of waste shipped off-site in the absence of a subsidy is q*. The delivered price of the waste is P. An off-site disposal subsidy has the effect of reducing the marginal cost curve from MC to MC′. With the subsidy, a new equilibrium is reached at q′. While the price paid for the waste remains unchanged, the subsidy increases the amount of waste that is shipped.

3.4 Composting Subsidy

Since composting substantially reduces the weight of the waste, it can also reduce shipping costs and make it more economically practical to transfer wastes from surplus to deficit regions. It should also make it cost-effective to ship wastes over farther distances. Figure 4 illustrates this. MC (uncomposted) represents the marginal cost of shipping a ton of waste from surplus to deficit areas. The increasing nature of the cost function is due primarily to the increasing distances that wastes must be shipped as greater quantities are produced. MC (composted) represents the marginal cost of shipping composted wastes. This value includes both the cost of composting and that of transport. The increased y intercept of MC (composted) over MC (uncomposted) represents the cost of composting. The lower slope of MC (composted) reflects the reduced per unit transport cost due to weight reduction achieved during composting. Over short distances the price advantage of the reduced shipping weights are not enough to overcome the composting costs, and it is more cost effective simply to transfer uncomposted wastes. This is illustrated by the fact that, until point B, MC (uncomposted) is less than MC (composted). After point B, however, the shipping costs begin to dominate and wastes are composted. However, since at point C the marginal cost exceeds the willingness to pay (P), only the small amount between B and C will be composted.

By subsidizing the composting process, the marginal cost of transferring composted waste shifts downward to MC′ (composted). This has two effects. First, it lowers the point at which composting becomes economical from B to A. Second, it increases the total amount of waste being shipped from C to D. As a result, it becomes cost-effective to transfer wastes over greater distances.

3.5 Nutrient Permit Trading

Under the nutrient permit trading scenario, an overall limit is placed on the amount of nutrients over the entire region. Each farmer is allotted a certain amount of allowable nutrients based on the absorption capacity of his land. The absorption

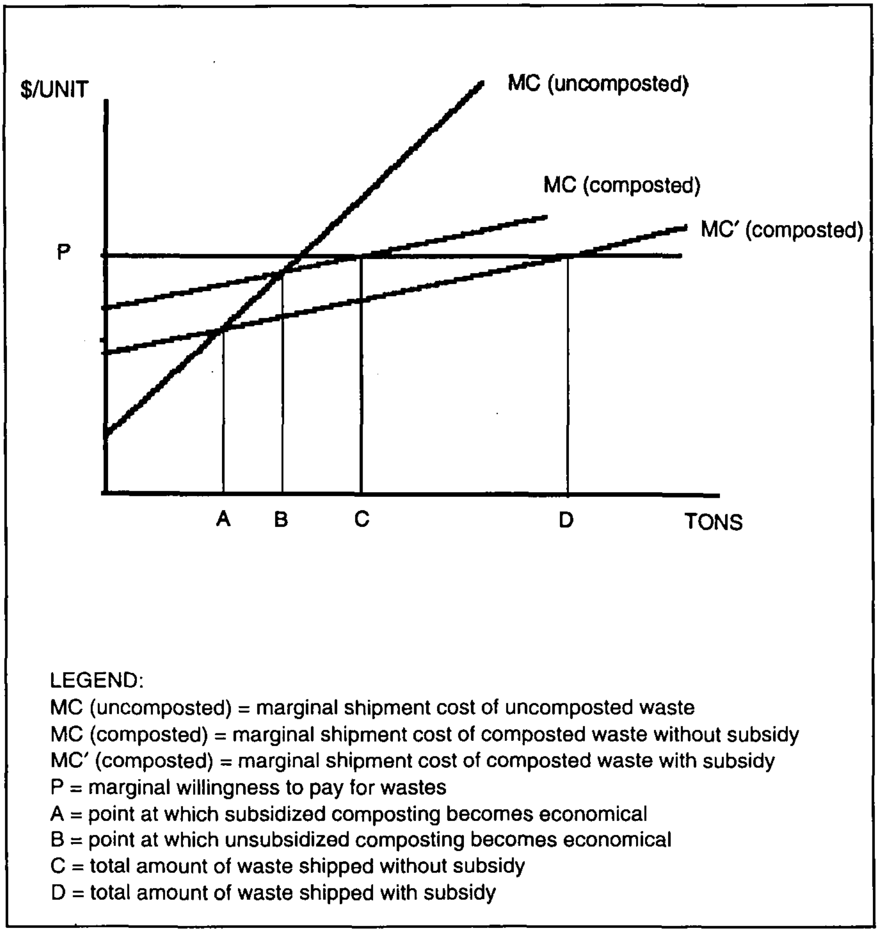


Figure 4. Composting subsidy.

capacity would be a function of the amount of cropland and pasture on the farm and the recommended amount of nutrient application per acre of the various crop types. A market for nutrient rights is then created whereby permits to discharge nutrients may be traded among farmers. Farmers wishing to use more than the allotted amount of nutrient must purchase the right to do so from the market. Those who use less may sell their rights to the market. Theoretically, since those with high marginal abatement costs would want to buy permits and those with low marginal abatement costs would want to sell them, the price of the permits should reach an optimal level whereby overall abatement is achieved at the most economically efficient level.

The permit trading scenario for a two player game is illustrated in Figure 5. Under the initial nutrient allotments both sources 1 and 2 must reduce their nutrient disposal by 5 units. The marginal cost of doing so for source 1 is A while for source 2 it is C. Under the permit trading system, player 2 may purchase the right to discharge extra nutrient units from player 1. This will occur until player 2's willingness to pay for nutrient rights no longer exceeds player 1's cost of abatement. This occurs at point B, where the marginal cost of abatement of each player is the same. Under such a system, theoretically, the overall pollution level will be obtained in the most economically efficient manner.

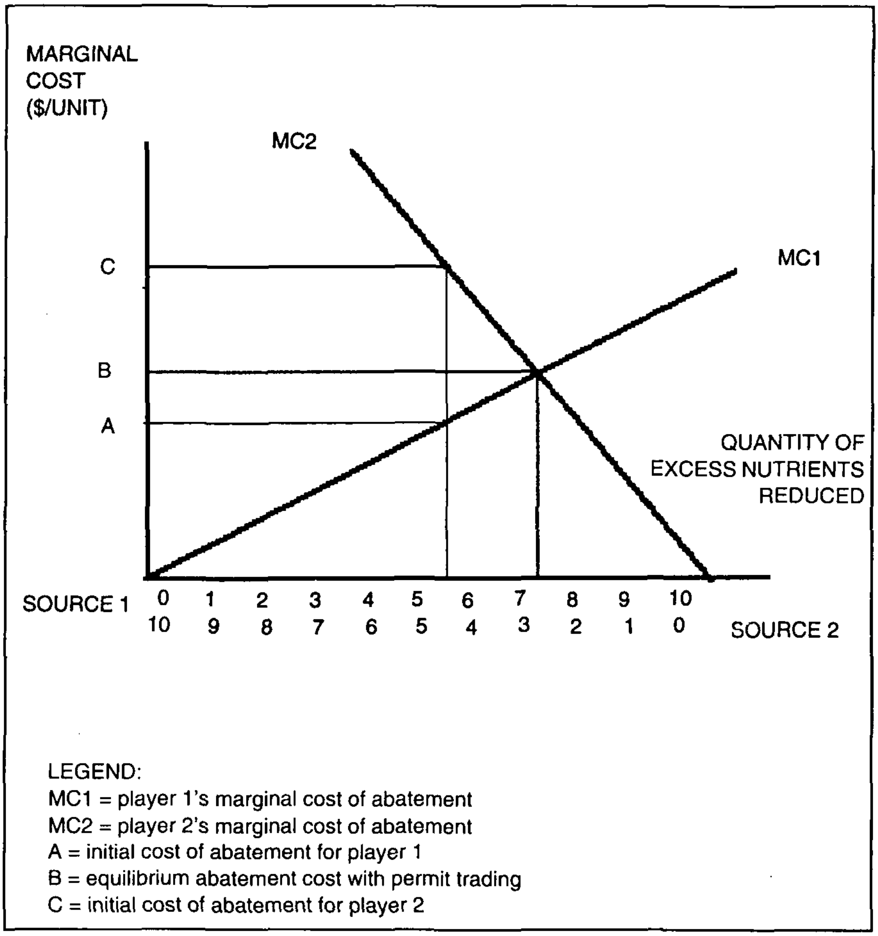


Figure 5. Nutrient permit trading.

4.0 IMPLEMENTATION ISSUES

This section provides a discussion of the implementational issues concerning the various policy alternatives. The purpose is to highlight the basic information, monitoring, and enforcement requirements to implement each of the scenarios. Political factors are also discussed.

4.1 Excess Nutrient Tax

Information Requirements

The information requirements for such a policy are considerable. Policy makers must first be able to determine the absorption capacity of each farm. Next, they must be able to track the amount of nutrients from all sources being applied to the land. That is, they must know the number of animals on each farm, the amount of nutrients produced by each animal, the amount of waste that stays on the farm, and the amount of nutrients applied to the land in the form of commercial fertilizers. Factors involved with each are discussed separately below.

Absorption capacity—This depends on several factors, including the size of the farm, the number of acres of various crops and pastureland on the farm, the absorptive capacity of the various crops, soil characteristics, the proximity to watersheds or other ecologically sensitive areas, etc. Many municipalities and counties already maintain statistics concerning farm sizes, croplands, and animal production. Such numbers are fairly straightforward and could be applied relatively easily. While estimates exist for recommended nutrient applications for the different types of crops, these are to some extent subjective. They are also, of course, only estimates. Actual requirements are extremely variable and are influenced by such factors as soil characteristics and weather conditions. Thus, the nutrient requirements for a given plot of land may vary considerably from one year to the next. Finally, environmental sensitivity is a difficult thing to measure and would likely be the subject of much political debate.

Animals on farm—This number is fairly straightforward. Municipalities and counties often maintain such records.

Nutrients per animal—Estimates exist for the average amount of waste produced by each type of animal and the average amount of nutrients in the wastes. These numbers are variable and depend on such factors as the size and diet of the animal. While not completely accurate, these averages are probably reasonable approximations for policy application.

Waste that stays on farm—Determining how much waste remains on the farm is basically a function of how much is produced minus how much is removed from the farm. Total production is determined by the factors already discussed. Determining how much leaves the farm requires keeping track of how much is shipped offsite minus any waste that is received from other farms. Such figures could be maintained by requiring the farmers to catalogue their waste shipments.

Commercial fertilizer application—Finally, farmers would be required to keep track of the amount of nutrients, in the form of commercial fertilizers, they purchase and apply to their fields. With proper accounting methods, this number should not be difficult to maintain.

Monitoring and Enforcement

While the initial data requirements pose problems themselves, much more difficult is the issue of enforcement. For each of the above data requirements, the government must be able to oversee and verify the numbers. This requires not only a substantial bureaucracy, but also a certain level of field inspection. It would be extremely difficult and expensive to enforce the various practices at the farm level.

Political Factors

Such a tax scheme represents a considerable invasion of the farmer's practice. Farmers who are used to making their own decisions concerning nutrient management would likely react quite negatively to regulations which not only require extensive monitoring, but are also based on recommended levels which in turn reflect arbitrary averages and may not pertain specifically to the farmer's needs.

Furthermore, taxes that are concentrated on farmers would likely face stiff opposition. Farmers would likely argue that society as a whole benefits from pollution reduction and that it is unfair to place the burden of paying for it solely on the farmers. Any tax that were implemented would likely be far below the level needed to truly address the pollution problem. While taxes which incorporate the true environmental costs of nonpoint pollution would be economically efficient, in practice such levels may be very difficult to implement.

4.2 Off-Site Disposal Subsidy

Information Requirements

In contrast to the nutrient tax scheme, the off-site disposal subsidy policy requires relatively little information. All that is required is that records be kept of the amount of each type of waste transported off-site. The desire of the farmer to receive the subsidy provides the incentive for proper record keeping.

Monitoring and enforcement—Since it is in the self interest of the farmer to maintain the records in order to obtain the subsidy, little enforcement is required. The only enforcement required is to ensure that farmers do not overstate the amount of waste shipped.

Political factors—Subsidies are common, particularly in agriculture. They have a general advantage in that they are relatively easy to implement, and are thus politically attractive. In contrast to other policies which impose costs on polluters, subsidies actually pay the polluters to change their activities. The costs of the subsidy are paid for by the general government coffers. Since the costs are paid diffusely by tax payers, there is not a concentrated organized interest group opposing them.

A subsidy can, however, have unintended and undesirable side-effects. According to Harrington et al.,

- It can provide payments to people to do things they would have done anyway. . . .
- *It can distort the mix of inputs used to achieve the desired objective.* Federal subsidies are usually for capital and not for operating costs, encouraging the selection of capital-intensive investments.
- Once established, subsidy policies are extremely difficult to revise or abandon. . . .
- All subsidy programs have the problem of defining the baseline against which future performance is to be measured. . . .
- A subsidy program can have unintended effects that negate some or all benefits . . . [12].

Since all of the subsidies investigated in this article provide incentives which make it easier and less expensive for farmers to handle animal wastes, they provide a potential disincentive for farmers to reduce the amount of waste produced.

4.3 Waste Transport Subsidy

As with the off-site disposal subsidy, relatively little information is required to implement the waste transport subsidy. Waste transporters must keep track of the amount of wastes they ship and the distances the wastes are moved. Since most transporters use such information already when they charge their customers, and since it would be in their interest to maintain the records in order to obtain the subsidy, very little infrastructure is required to implement the policy. Monitoring and enforcement can be performed through auditing of the transporters' recordbooks. The political factors and side effects related to the subsidies discussed in the case of the off-site disposal subsidy also apply to the case of the waste transport subsidy.

4.4 Composting Subsidy

Here, the information required is the amount of each type of waste that is composted. Composting may occur on-farm or at a centralized facility. In the case of the centralized facility, the operator would charge a subsidized price for waste that is brought by the farmer. In the case of on-farm composting, the farmer must be relied upon to maintain accurate records of the amount of waste he composts. For this case, a certain amount of on-site inspection may be required in order to monitor that the figures submitted by the farmers are accurate. The politics of this policy should be relatively benign.

4.5 Nutrient Permit Trading

Like the nutrient tax scenario, a nutrient permit trading system would entail significant data requirements. As in that case, policymakers would need to know the nutrient absorption capacity of each farm, the number of animals on the farm, the nutrients per animal, the amount of waste that remains on the farm, and the amount of fertilizer application. It would also be subject to the same monitoring and enforcement difficulties associated with such information control. In this case, however, an added level of bureaucracy is needed as the government must keep track of the trading of permits among the various players.

Some of the implementational issues regarding application of permit trading mechanisms to nonpoint sources are referred to by Harrington et al.:

> First, target loadings for the group need to be established. Second, the pollution control agency must be able to monitor discharges by the group. Third, market organizations to minimize transaction costs and maximize participation need to be devised. . . . Fourth, more information on the transport and fate of pollutants is needed to establish the boundaries of trading areas. Fifth, a level of loadings, called a baseline, must be established from which reductions in pollution can be credited. . . . Agricultural sources . . . do not generally face maximum allowable loading requirements. Thus, baselines based on actual practice must be determined . . . [12].

Another problem with trading nonpoint source pollution (as was the case for the excess nutrient tax) is that pollutant levels are strongly weather dependent. Pollutant concentrations of soils will vary considerably between rainy and drought conditions. This problem makes nonpoint sources much more difficult to monitor than point sources that might come out of a pipe or a smokestack. Also, in an area where there are several potential polluters, it is difficult to determine from soil samples who is responsible for the pollution.

Aside from the fact of farmers not wanting to be regulated, and the enormous information and monitoring requirements, the permit trading approach suffers from another potential problem. Namely, a considerable amount of education and outreach would be required to explain to farmers how the system works. Although the agricultural extension service provides the infrastructure for such an effort, the undertaking would likely be extremely difficult and would meet opposition from those who resent interference and do not want to change their mode of operation.

Watershed-based point-nonpoint trading schemes have been developed in some areas, most notably at Lake Dillon, Colorado and Tar-Pamlico, North Carolina.

Under such schemes, trading occurs predominantly among point source polluters, but those traders may apply reductions in nonpoint source nutrient loadings toward their nutrient credits. At Lake Dillon, a 2:1 ratio is developed whereby two pounds of nonpoint reductions must be achieved for every pound of credit obtained [13]. At Tar-Pamlico, point sources may purchase pollution credits by paying a fixed cost to a fund that implements nonpoint source controls through the state's agriculture cost share program. Such systems have appeal in that they avoid many of the implementational difficulties of the purely nonpoint trading system presented here. As a general rule, as permit trading shifts farther from point source based to nonpoint based, the associated implementational difficulties increase considerably.

4.6 Market Inefficiencies

The theoretical discussions of Section 3.0 assumed a fully efficient market. If, however, market inefficiencies exist, the theoretical appeal of market mechanisms may diminish. In particular, market incentives may have little effect if the information costs associated with finding markets for wastes are high; the reader is referred to Norman for an analysis which shows that informational and other market inefficiencies are indeed high [14]. In cases where information costs are substantial, it may be more cost-effective to implement strategies to reduce the inefficiencies. Market surveys that may be used to identify potential suppliers and demanders of waste, and education concerning the importance of nutrient management, are two such strategies.

Reasons why the market for animal wastes and fertilizers may not be efficient include imperfect information concerning where the markets for waste are, the relative convenience of purchasing commercial fertilizer, localized over-application of nutrients, improper on-farm management practices which allow nutrients to enter surface and groundwaters, and factors related to seasonality of nutrient demand. The demand for nutrients is greatest in the spring before planting and the fall after harvest. However, animal wastes are produced year-round. Disposal of wastes is often impossible in the winter due to snow coverage, and is difficult when soils are wet. Since it is generally during these pre-planting and post-harvest windows of opportunity that much of the waste is likely to be transported, it is difficult to develop the high level of transporting infrastructure for these peak periods which will be used only minimally during much of the rest of the year.

5.0 CONCLUSION

This article has provided a theoretical and implementational discussion of several potential market-based mechanisms to reduce nonpoint source nutrient pollution. Market incentives have theoretical appeal in that, if set at the proper level, they compel polluters to reduce pollution generation to the socially efficient level automatically. However, as discussed, each such mechanism has associated with it implementational factors which must be overcome. In addition, market inefficiencies may reduce the practical effectiveness of market-based incentives. In cases where informational costs are high, alternative approaches (such as market surveys and education) aimed at reducing those costs may be required.

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Direct reprint requests to:

Dr. Marc E. Norman
1915 Sixteenth St., NW, #301
Washington, D.C. 20009