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A SPATIAL PRICE EQUILIBRIUM ANALYSIS OF MARKET-BASED INCENTIVES TO ABATE NONPOINT SOURCE AGRICULTURAL NUTRIENT POLLUTION

MARC E. NORMAN

JOHN D. KEENAN

PATRICK T. HARKER

University of Pennsylvania, Philadelphia

ABSTRACT

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. One of the principal means to reduce nonpoint nutrient pollution is through the application of market incentives. In this article, computable spatial price equilibrium models are developed to analyze the effects of various market incentive schemes to reduce agricultural nutrient pollution. The models are applied empirically to an agricultural subsector of southeastern Pennsylvania. Based on the results of the analysis, and on issues regarding implementation, policy recommendations are developed.

1.0 INTRODUCTION

In contrast to the marked improvements made in controlling industrial and municipal water pollution over the past two decades, agricultural-based pollution remains a significant problem. According to EPA estimates, in fact, only 15.1 percent of impaired lake acres in the United States are now affected by pollution from municipal point sources, and only 7.7 percent by pollution from industrial sources; by contrast, pollution from agriculture, which is the major contributor, affects 58.2 percent. Nutrients such as nitrogen, phosphorus, and potassium are the primary causes of lake pollution, affecting 48.8 percent of impaired lake acres [1]. According to the National Research Council [2], between 50 to 70 percent of

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all nutrients reaching surface waters have been estimated to originate on agricultural land in the form of fertilizer or animal waste. Accordingly, nutrients associated with agricultural animal wastes and fertilizers are among the most widespread causes of water pollution today.

Nutrients are necessary for proper plant growth. In excess amounts, however, they can cause several environmental problems. Nitrogen may occur in many forms, including nitrates (NO_3-N), nitrites (NO_2-N), and ammonium (NH_4-N). All forms of nitrogen can cause eutrophication of aquatic plantlife. Dissolved ammonia may be toxic to fish. Nitrates in drinking water are potentially dangerous, especially to newborn infants and animals. Nitrate is converted to nitrite in the digestive tract, which reduces the oxygen-carrying capacity of the blood (methemoglobinemia), resulting in brain damage or even death in newborn infants and animals. Phosphorus, like nitrogen, contributes to eutrophication. It is considerably less mobile than nitrogen, and can build up in the soil when applied in excessive amounts. It is introduced into waterways primarily through soil erosion.

Traditionally, there have been no regulatory controls on nonpoint nutrient loadings. Most waste has been spread as raw manure on farmland. Fertilizer has been spread with little incentive to internalize its broader environmental effects. The diffuse nature of nonpoint discharges and the associated monitoring costs have until recently precluded nonpoint regulation and enforcement. New federal statutes, however, are forcing states to confront these issues. The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) were enacted to confront what was considered a dramatic decline in coastal area drinking water quality. Section 6217 of the act requires that coastal states develop a Coastal Nonpoint Pollution Control Program, for approval by the Environmental Protection Agency and the National Oceanic and Atmospheric Administration. As part of the nonpoint program, the states must develop a comprehensive nutrient management plan. The state programs must be fully implemented by January 2004.

Regulators have several policy options by which to control nonpoint source pollution, including direct command and control interventions which regulate the practices and technologies farmers may use, market-based approaches such as taxes, subsidies, or tradable permits, and a more voluntary approach based on education and moral suasion. Market-based approaches are particularly attractive in that, if set at the proper level, they allow the market to adjust automatically to the most socially efficient level. The purpose of the article is to analyze the effects of various market-based mechanisms that may be implemented to reduce nonpoint source nutrient pollution. To make the analysis directly applicable to states that must develop nonpoint source programs under the new regulations, the analysis is applied empirically to an agricultural subsector of Pennsylvania. The analysis of Pennsylvania is also particularly salient due to the recently enacted Pennsylvania Nutrient Management Act of 1993.

The purpose of this article is to present a computational equilibrium model that will be used to answer the following questions:

1. What are the effects, in terms of cost and pollution abatement, of various market mechanisms (nutrient taxes, off-site disposal subsidies, waste transport subsidies, compost subsidies) to reduce nonpoint source nutrient pollution associated with agricultural animal wastes and fertilizers?
2. What are the noncooperative game-theoretic flows and prices of wastes in an agricultural subsector of Pennsylvania under the different policy alternatives?
3. How can complementarity spatial price equilibrium programming techniques be applied to answer questions 1 and 2?
4. Based on the results of the analysis, and on issues regarding implementation, what are the recommended policies to reduce nonpoint source nutrient pollution?

The next section will review the relevant literature, Section 3.0 will present the computable equilibrium model, the application of the model will be described in Section 4.0, and policy recommendations based on this model will be presented in the last section.

2.0 REVIEW OF RELATED RESEARCH

For purposes of categorization, the pertinent literature is classified according to research performed concerning nonpoint source pollution control and animal waste transport models.

2.1 Nonpoint Source Pollution Control Studies

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 [3].

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.

Further research concerning nonpoint source pollution control strategies include Coffey et al. [4], who discuss the elements of a model program for nonpoint source pollution control based on the RCWP experience, and Young et al. [5], 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 [6]. Shortle and Dunn examine the relative expected efficiency of four general strategies for achieving agricultural nonpoint pollution abatement [7]. 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 [8]. 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 [9]. 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 [10]. Lanyon et al., at Pennsylvania State University, have performed considerable studies concerning on-farm nutrient management. Their most relevant research is a linear programming analysis concerning the plant nutrient management strategy implications for optimal herd size and performance of a simulated dairy [11]. 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 [12]. Finally, Just and Antle developed a conceptual framework to analyze the interactions between agricultural and environmental policies and pollution [13].

2.2 Animal Waste Transport Models

Spatial price equilibrium models have been used widely to analyze various aspects of the agriculture sector. Classic treatises include Takayama and Judge [14], Hall, Heady, and Plessner [15], and Hall et al. [16]. Despite this substantial literature, however, no comparable model has been developed for the case of animal waste management. Recent studies in this area have begun to model certain aspects of markets for animal waste, but to date have been limited to simple fixed-price linear and nonlinear programming analyses. No analysis has investigated the effects of various environmental regulatory mechanisms upon regional animal waste markets.

The most advanced modeling of animal waste transport has been performed by de Mol and van Beek [17]. They developed linear and nonlinear optimization models to analyze the animal waste handling system in the Netherlands. The research was motivated by a considerable phosphorus pollution problem due to extensive livestock production. The objective function of their models was to minimize overall cost. The models were used to develop strategic decisions, such as investments relating to centralized storage, treatment, and processing, and tactical decisions concerning optimal use of existing infrastructure.

Other pertinent research includes a linear programming model developed in a Doctoral dissertation by Napit [18] and published by Bosch and Napit [19] which analyzed the economics of transporting poultry litter in the state of Virginia. They calculated the supply of litter and the amount of available farmland for each county. Their objective function was

$$\mathrm{MIN}(TC = \Sigma_i \Sigma_j C_{ij} X_{ij})$$

s.t.

$$\Sigma_j X_{ij} = X_i \qquad \text{for } i = 1,2,\ldots m$$
$$\Sigma_i a_{ij} X_{ij} \le X_j \qquad \text{for } j = 1,2,\ldots n$$

where C_{ij} equals the per Mg cost of making litter from the i^{th} county available for fertilizer in the j^{th} deficit county; m is the number of surplus counties; n is the number of litter deficient counties; X_{ij} represents the amount of litter transferred from surplus county i to deficit county j; X_i is the amount of litter available for export from surplus county i; X_j is the amount of nitrogen required from external applications by crops in deficit county j; and a_{ij} is the amount of nitrogen taken up by the crops per Mg of applied litter. The objective function states that the firm seeks to minimize its total costs of transferring a fixed amount of litter. The first constraint requires the firm to transfer all surplus litter from surplus to deficit counties. The second constraint states that no county can receive more litter than it has potential to use nitrogen on cropland or pasture. From this analysis, the authors concluded that export of litter from surplus to deficit areas for use as fertilizer was economically viable in Virginia.

2.3 Facts Concerning the Study Area

The empirical analysis described in Section 4.0 was performed over the ten county agricultural subsector of Pennsylvania shown in Figure 1. Lancaster County was chosen because of its status as the county with the most extensive livestock production in Pennsylvania. The remaining nine counties were chosen due to their proximity to Lancaster County. This region is also environmentally important in that it drains into the Susquehanna River Basin, which is a primary water source of the Chesapeake Bay. Nutrients from this region are one of the leading causes of pollution in the Bay. Calculations for the annual amount of nutrients produced by livestock and the recommended annual amount of nutrient inputs for each county were developed in Norman [20]. The results are presented in Tables 1 and 2, respectively. Annual commercial fertilizer sales for the different counties are presented in Table 3. Detailed data on this area will be used in Section 4.0 to illustrate the use of the proposed model for policy analysis.

3.0 A COMPUTABLE EQUILIBRIUM MODEL FOR NONPOINT SOURCE POLLUTION MARKETS

In this section, a computable equilibrium model for the nonpoint source market will be developed using the concepts of complementarity programming. The general approach of complementarity programming is to develop a set of non-cooperative equilibrium conditions for the market. To do this, welfare functions of the individual players, and the constraints to which they are subject, are first developed. Next, using Lagrange multipliers, first order conditions are generated. The first order conditions provide the conditions under which the welfare of the individual player is maximized. Finally, market-clearing conditions are generated

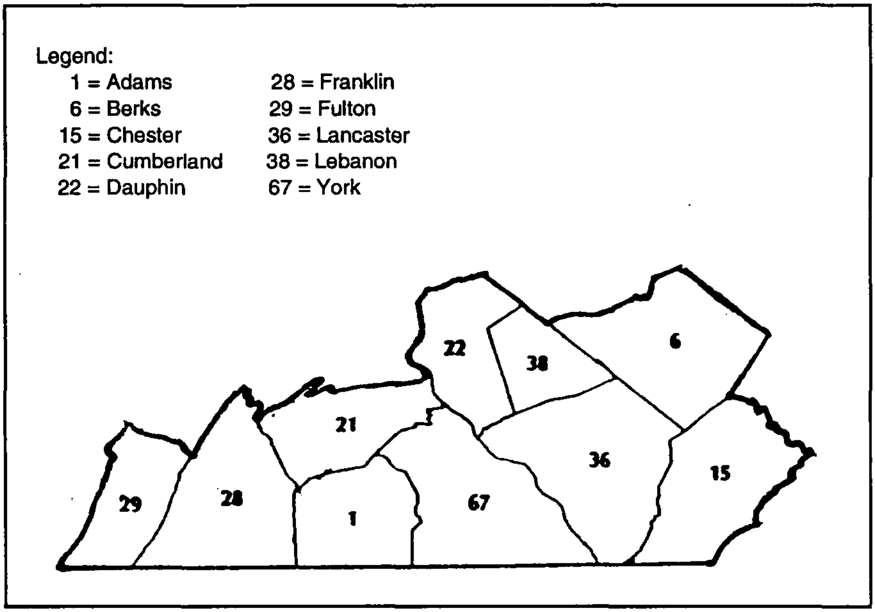

Figure 1. Study area.

Table 1. Amount of Nutrients Producted by Livestock in Each County (Tons/Year)

	Nitrogen	Phosphate	Potash
Dauphin	1490.95	1235.41	1103.37
Adams	2656.15	2525.14	1964.34
Cumberland	2072.24	1425.81	1683.00
Franklin	4163.36	2941.79	3349.52
Fulton	648.56	381.89	553.95
York	2686.36	1930.13	2134.85
Berks	3445.31	2442.43	2707.03
Chester	2254.68	1467.27	1849.05
Lancaster	20358.01	17080.94	14925.99
Lebanon	4161.09	3462.16	3009.15

Table 2. Recommended Nutrient Amount for Each County (Tons)

	Nitrogen	Phosphate	Potash
Dauphin	5547.50	2040.03	4169.85
Adams	8561.00	2847.07	5416.35
Cumberland	9097.25	3415.25	7043.75
Franklin	14794.75	5366.82	11316.40
Fulton	4470.25	1445.85	3050.45
York	15025.50	5386.69	9616.85
Berks	14193.50	4898.92	9333.95
Chester	10852.50	3592.25	7310.15
Lancaster	25305.00	9556.78	19297.35
Lebanon	7505.50	2751.05	5673.85

Table 3. Commercial Fertilizer Sales (Tons)
July 1992-June 1993
(Pennsylvania Department of Agriculture, 1993)

	Nitrogen	Phosphate	Potash
Dauphin	1072	766	534
Adams	7292	7774	2867
Cumberland	1691	1396	1105
Franklin	4037	3009	2719
Fulton	99	90	85
York	5166	2686	2922
Berks	2265	1207	1537
Chester	3204	2068	2415
Lancaster	7993	3723	4766
Lebanon	622	546	483

by taking the Lagrangian with respect to price. With these various conditions set, the overall equilibrium for the market is computed.

Harker provides the following definition of the complementarity problem:

> *Definition:* Let F be a mapping from R^n into itself. The nonlinear complementarity problem, denoted by NCP (F), is to find a vector $x^* \varepsilon R^n_+$ such that:
>
> $$F(x^*) \varepsilon R^n_+ \text{ and } F(x^*)^T x^* = 0.$$

When F(x) is an affine function of x, say $F(x) = q+Mx$ for some given vector $q \varepsilon R^n$ and matrix $M \varepsilon R^{nxn}$, the problem NCP (F) reduces to the linear complementarity problem, which is denoted by LCP(q,M):

$$x \geq 0, \quad q+Mx \geq 0, \quad x^T(q+Mx) = 0$$ [21].

where,

R^n = an n-dimensional Euclidean space;

R^n_+ = the positive orthant of R^n, i.e., the subset of R^n of vectors in which each component is nonnegative.

The models used in this paper are of this linear complementarity structure. The reader is referred to the Harker monograph for a further discussion of complementarity programming [21]. Cottle, Pang, and Stone [22] and Murty [23] also both provide extensive discussions of the theory and structure of the linear complementarity problem. Rutherford provides a guide to running complementarity models using GAMS[1] software [24]. The program is written in GAMS and run using the MILES solver.

The key advantage of complementarity programming over tradition linear or nonlinear optimization techniques is that it allows for the development of non-cooperative equilibria in which market clearing flows and prices of goods are determined. Traditional optimization techniques, in contrast, require the unrealistic assumption that the players will act in a way that optimizes the objective function placed on the overall system. The complementarity approach further allows for the analysis of the effects of government policy interventions on the market equilibria flows and prices.

3.1 Model Formation

The base scenario and subsequent policy scenarios are outlined below. For purposes of manageability, and due to data constraints in the application, the players in the models are aggregated to the county level.[2] In reality, the decision makers would be the individual farmers. The notation utilized is defined as follows:

h = waste type (dairy, cattle, swine, sheep, broiler, layer)
i = j = list of counties
k = commercial fertilizer type
m = type of nutrient (nitrogen, phosphorus, potassium)
$SNON_{hij}$ = quantity of uncomposted waste type h supplied by county i to county j

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[1] GAMS is an acronym for General Algebraic Modeling System.

[2] The primary drawbacks of this aggregation are a loss of sensitivity to localized livestock and crop distributions, and the inability to study intracounty waste shipments.

$SCOM_{hij}$ = quantity of composted waste type h supplied by county i to county j
$DNON_{hi}$ = quantity of uncomposted waste type h demanded at county i
$DCOM_{hi}$ = quantity of composted waste type h demanded at county i
z_{ik} = quantity of commercial fertilizer of type k utilized in county i
$TNON_{hij}$ = transportation cost per unit of uncomposted waste type h
$TCOM_{hij}$ = transportation cost per unit of composted waste type h
C_h = cost of composting waste type h
$NUTNON_{hm}$ = quantity of nutrient type m per unit of uncomposed waste type h
$NUTCOM_{hm}$ = *quantity of nutrient type m per unit of composted waste type h*
$NUTF_{km}$ = quantity of nutrient type m per unit of commercial fertilizer type k
F_k = cost per unit of commercial fertilizer
REC_{im} = recommended quantity of nutrient type m in county i
$AMOUNT_{hi}$ = quantity of waste type h generated in county i
$PNON_{hi}$ = price of uncomposted waste type h at county i
$PCOM_{hi}$ = price of composted waste type h at county i
$EXCESS_{im}$ = quantity of nutrient type m in excess of recommended amount in county i
Θ_{im} = Lagrange multiplier for the nutrient balance constraint = marginal value of nutrient m at county i
Ψ_{hi} = Lagrange multiplier for the waste balance constraint = marginal value of waste h at county i
$\perp$ = orthogonality condition, where "X $\perp$ Y" signifies that X and Y are orthogonal; i.e., X·Y=0.

3.2 Base Scenario

Under free-market conditions, each county wishes to maximize welfare as follows:

$$\text{MAX } (\Sigma_{hj}(PNON_{hj}-TNON_{hij})SNON_{hij} + \Sigma_{hj}(PCOM_{hj}-C_h-TCOM_{hij})SCOM_{hij} - \Sigma_k F_k Z_{ik} - \Sigma_h PNON_{hi} DNON_{hi} - \Sigma_h PCOM_{hi} DCOM_{hi})$$

s.t.

$$\Sigma_h AMOUNT_{hi} NUTNON_{hm} + \Sigma_h DNON_{hi} NUTNON_{hm} + \Sigma_h DCOM_{hi} NUTCOM_{hm} + \Sigma_k Z_{ik} NUTF_{km} - REC_{im} - \Sigma_{hj} SNON_{hij} NUTNON_{hm} - \Sigma_{hj} SCOM_{hij} NUTCOM_{hm} - EXCESS_{im} = 0$$

$$AMOUNT_{hi} - \Sigma_j SNON_{hij} - \Sigma_j SCOM_{hij} = 0$$

$$SNON_{hij} \geq 0;\ SCOM_{hij} \geq 0;\ DNON_{hi} \geq 0;\ DCOM_{hi} \geq 0;\ Z_{ik} \geq 0$$
$$EXCESS_{im} \geq 0;\ P_{hi} \geq 0$$

The first two terms of the objective function represent the profits made by selling uncomposted and composted wastes, respectively. The third term is the cost of purchasing commercial fertilizer. The final two terms are the costs of buying uncomposted and composted wastes, respectively. The first constraint is the nutrient balance constraint. Since EXCESS_{im} is nonnegative by definition, this constraint states that, for each type of nutrient, the amount imported as waste plus the amount purchased as fertilizer minus the amount sold as waste to other counties must be greater than or equal to the difference between the recommended amount and the initial endowment for county i. In other words, each county must receive at least its recommended amount of each nutrient required for proper crop growth. The second constraint is the balance constraint for wastes. It simply states that the total amount of waste type h supplied by county i must equal the amount produced in that county. In other words, all waste must be disposed of somewhere. The final set of constraints are the nonnegativity conditions.

The first order conditions for the base scenario, developed by taking the Lagrangian with respect to SNON_{hij}, SCOM_{hij}, Z_{ik}, DNON_{hi}, and DCOM_{hi}, respectively, are as follows:

$$\text{PNON}_{hj} - \text{TNON}_{hij} - \Sigma_m \text{NUTNON}_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \quad \perp \text{SNON}_{hij} \geq 0$$

$$\text{PCOM}_{hj} - \text{TCOM}_{hij} - C_h - \Sigma_m \text{NUTCOM}_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \quad \perp \text{SCOM}_{hij} \geq 0$$

$$-F_k + \Sigma_m \text{NUTF}_{km}\Theta_{im} \leq 0 \quad \perp Z_{ik} \geq 0$$

$$-\text{PNON}_{hi} + \Sigma_m \text{NUTNON}_{hm}\Theta_{im} \leq 0 \quad \perp \text{DNON}_{hi} \geq 0$$

$$-\text{PCOM}_{hi} + \Sigma_m \text{NUTCOM}_{hm}\Theta_{im} \leq 0 \quad \perp \text{DCOM}_{hi} \geq 0$$

Where "$X \perp Y$" signifies that X and Y are orthogonal; i.e., $X \cdot Y = 0$. The first of these states that, in equilibrium, the price of uncomposted waste type h at some county j must be equal to or less than the price of transporting the waste from i to j plus the total value of the nutrients in the waste at county i plus the opportunity cost of not selling the waste elsewhere. If the price at j were greater than the sum of these costs, county i would have an incentive to sell more waste to j and the market would not be in equilibrium. The orthogonality condition ($\perp$) requires that when SNON_{hij} is strictly positive, the equation becomes a strict equality. This means that if waste is transferred from i to j, the price received must equal the sum of the direct costs incurred plus the opportunity costs to county i. If, at equilibrium, the condition is strictly negative, this indicates that the costs to county i are greater than what county j is willing to pay for the waste. In that case the quantity shipped from i to j will be strictly zero. The sum of the terms to the left of the inequality may, for each of the conditions, be considered the reduced cost of the corresponding variable to which the equation is orthogonal.

The second first-order condition is similar to the first, except that it applies to wastes that are composted. In this case per unit transportation costs are lower due to the mass reduction during the composting process. In this case, however, the costs associated with composting the wastes must also be included.

The third first-order equilibrium condition states that, for county i, the marginal benefits of the nutrients in a given fertilizer must be equal to or less than the price of the fertilizer. If county i purchases the fertilizer, the marginal benefits of the nutrients will be equal to the price of the fertilizer. If the marginal value is less than the fertilizer cost, then county i will not buy that fertilizer. Again, if the marginal value were greater than the fertilizer cost, the system would not be in equilibrium since the county would have the incentive to purchase more of the fertilizer.

The fourth first-order condition states that, for a given type of uncomposted waste, the marginal value of its nutrients must be less than or equal to the price of the waste at i. If, in equilibrium, county i demands waste type h, then the equation becomes a strict equality. If the costs exceed the marginal value then county i will have zero demand for waste type h. The final condition is similar to the fourth except that it applies to composted wastes.

In addition to the first-order conditions, the system is also subject to the following market-clearing conditions:

$$\mathrm{DNON}_{hi} \leq \Sigma_j \mathrm{SNON}_{hij} \perp \mathrm{PNON}_{hi} \geq 0$$

$$\mathrm{DCOM}_{hi} \leq \Sigma_j \mathrm{SCOM}_{hij} \perp \mathrm{PCOM}_{hi} \geq 0$$

According to the first market-clearing condition, if there is a positive price for uncomposted waste type h at county i, the sum of the quantity supplied to i must equal the demand at i. If, in equilibrium, the willingness of other counties to supply waste type h exceeds the demand at i, then the price of waste h at county i must be zero. The second condition establishes the same relationship for composted wastes.

With the various constraints and conditions developed, the complementarity program can be written and solved to establish the free-market flows and clearing prices of wastes. It further provides the theoretical cost-effectiveness of the wastes vis-à-vis commercial fertilizers, and shows where and how far it is economically viable to transport composted and uncomposted wastes. Also, by keeping track of the excess nutrients, the model provides an estimate of the overall pollution that results in the absence of government intervention.

This base scenario provides a standard with which to compare the later scenarios in which government policies are incorporated. The results of this scenario will also be compared to the distribution of utilization that occur in actuality.

3.3 Policy Scenarios

The modeling approaches for the various policies to be analyzed are set forth below.

3.3.1 Excess Nutrient Tax

The first policy is to place a tax on excess nutrients. For this scheme, the objective function for county i becomes

$$\begin{gathered}\mathrm{MAX}\ (\Sigma_{hj}(PNON_{hj} - TNON_{hij})SNON_{hij} + \Sigma_{hj}(PCOM_{hj} - C_h - \\ TCOM_{hij})SCOM_{hij} - \Sigma_k F_k Z_{ik} - \Sigma_h PNON_{hi} DNON_{hi} - \\ \Sigma_h PCOM_{hi} DCOM_{hi} - \Sigma_m TAX_m EXCESS_{im})\end{gathered}$$

The first-order condition with respect to $EXCESS_{im}$ is

$$-TAX_m - \Theta_{im} \leq 0 \ \perp \ EXCESS_{im} \geq 0$$

Thus, if in equilibrium county i has an excess of nutrient m in the form of processed waste or commercial fertilizer, the tax on that nutrient must equal the disutility of the nutrient at county i. If the tax were less than the disutility of the nutrient, then the county would have the incentive to increase its nutrient excess until the two were equal. If the tax is strictly greater than the disutility, then the county would sell all its excess, and $EXCESS_{im}$ would be zero.

3.3.2 Off-Site Disposal Subsidy

In this case, the welfare function of each county becomes

$$\begin{gathered}\mathrm{MAX}\ (\Sigma_{hj}(PNON_{hj}+SUBS-TNON_{hij})SNOW_{hij} + \Sigma_{hj}(PCOM_{hj}+SUBS-C_h- \\ TCOM_{hij})SCOM_{hij} - \Sigma_k F_k Z_{ik} - \Sigma_h PNON_{hi} DNON_{hi} - \Sigma_h PCOM_{hi} DCOM_{hi})\end{gathered}$$

where SUBS is the subsidy provided per ton of waste disposed of off-site. The constraints remain the same as in the base scenario. In this case, however, the first-order conditions with respect to $SNON_{hij}$ and $SCOM_{hij}$ become

$$PNON_{hij} + SUBS - TNON_{hij} - \Sigma_m NUTNON_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \ \perp \ SNON_{hij} \geq 0$$

$$PCOM_{hj} + SUBS - TCOM_{hij} - C_h - \Sigma_m NUTCOM_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \perp SCOM_{hij} \geq 0$$

The first of these states that, in equilibrium, the price received for uncomposted waste type h at some county j plus the off-site disposal subsidy must be equal to or less than the price of transporting the waste from i to j plus the total value of the nutrients in the waste at county i plus the opportunity cost of not selling the waste elsewhere. The second first-order condition is similar to the first, except that it refers to composted wastes, and thus incorporates the cost of composting. In each case, the orthogonality condition, as explained in Section 3.2, still applies. The market-clearing conditions of the base scenario remain unchanged.

3.3.3 Waste Transport Subsidy

In this case the transport subsidy is incorporated directly into the transportation costs $TNONSUBS_{hij}$ and $TCOMSUBS_{hij}$, and the objective of the individual player becomes

$$\begin{gathered}\text{MAX}\ (\Sigma_{hj}(PNON_{hj}-TNONSUBS_{hij})SNON_{hij} + \\ \Sigma_{hj}(PCOM_{hj}-C_h-TCOMSUBS_{hij})SCOM_{hij}) - \Sigma_k F_k Z_{ik} - \\ \Sigma_h PNON_{hi} DNON_{hi} - \Sigma_h PCOM_{hi} DCOM_{hi}).\end{gathered}$$

Again, the constraints and market-clearing conditions remain unchanged, but the first-order conditions with respect to $SNON_{hij}$ and $SCOM_{hij}$ become

$$PNON_{hj} - TNONSUBS_{hij} - \Sigma_m NUTNON_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \ \perp SNON_{hij} \geq 0$$

$$PCOM_{hj} - TCOMSUBS_{hij} - C_h - \Sigma_m NUTCOM_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \ \perp \ SCOM_{hij} \geq 0.$$

3.3.4 Compost Subsidy

Another possible strategy would be to subsidize waste composting. Since composted waste weighs considerably less than uncomposted waste, this should have the effect of increasing the cost effectiveness of transporting wastes over longer distances. In this case the waste compost subsidy ($COMPSUBS_h$) is included into the individual county's objective function as follows

$$\begin{gathered}\text{MAX}\ (\Sigma_{hj}(PNON_{hj}-TNON_{hij})SNON_{hij} + \\ \Sigma_{hj}(PCOM_{hj}-C_h+COMPSUBS_h-TCOM_{hij})SCOM_{hij} - \\ \Sigma_k F_k Z_{ik} - \Sigma_h PNON_{hi} DNON_{hi} - \Sigma_h PCOM_{hi} DCOM_{hi})\end{gathered}$$

The constraints, first-order conditions, and market-clearing conditions of the base scenarios are retained, except that the first order condition with respect to $SCOM_{hij}$ becomes

$$\begin{gathered}PCOM_{hj} - TCOM_{hij} - C_h + COMPSUBS_h - \Sigma_m NUTCOM_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \\ \perp \ SCOM_{hij} \geq 0\end{gathered}$$

This equation states that, in equilibrium, the price received for uncomposted waste type h at some county j must be equal to or less than the price of transporting the waste from i to j plus the cost of composting minus the compost subsidy plus the total value of the nutrients in the waste at county i plus the opportunity cost of not selling the waste elsewhere. The orthogonality condition with respect to $SCOM_{hij}$ still holds.

3.4 Assumptions

The model relies on certain assumptions and does not incorporate several notable factors:

- The model assumes that commercial fertilizers and animal wastes can be used as perfect substitutes. There are, however, important differences. Most notably, depending on the form of the waste, the timing of nutrient release may vary considerably. Thus nutrients applied as waste in one year may not be available to crops until the following year. The model does not incorporate this intertemporal effect.

- The model is static in that it does not incorporate player responses to market incentives in terms of changes in animal numbers or reallocation of croplands. While omitted for simplicity, such secondary effects are potentially very important. Further research is needed to quantify these effects.
- The model does not incorporate the value of other soil enhancing attributes of animal wastes besides as a source of nutrients. It also does not incorporate other potential environmental costs associated with the wastes such as heavy metals or bacterial disease transmission.
- The model does not incorporate other potential uses of animal wastes, such as animal feed or bioenergy source.
- The model does not incorporate other nutrient management techniques such as crop rotation which affect the amount of nutrients in the soil from one crop planting to the next.
- Finally, the model does not incorporate the stochastic nature of weather and soil conditions which can affect the amount of nutrients absorbed by crops and the amount lost through runoff or leaching.

4.0 APPLICATION

This section describes the use of the models in Section 3 to the study area outlined in Section 2.3. The parameters in the model for which exogenous data are required are the recommended amount of nutrients used in each county (REC_{im}); the amount of each type of waste generated in each county ($AMOUNT_{hi}$); the amount of each nutrient per unit of each type of waste (NUT_{hm}); the amount of nutrients available in various commercial fertilizers ($NUTF_{km}$); the per unit costs of the commercial fertilizers (F_k); waste transportation costs (T_{hij}); and the per unit costs of composting the wastes (C_h). The methods and data sources used for determining values for each of these parameters are presented below. A summary of data obtained from outside sources is presented in Table 4. For the methodologies used to calculate the parameters from these data, the reader is referred to Norman [20].

The results of the analysis are presented below. Section 4.1 presents the base scenario, Section 4.2 discusses the apparent effects of information and inefficiency costs, and Section 4.3 through 4.6 discuss the various policy alternatives.

4.1 Base Scenario

The results of the base model are presented below in terms of intercounty waste flows, nutrient levels, waste prices, sensitivity to commercial fertilizer prices, sensitivity to nutrient absorption capacities, and sensitivity to livestock production levels.

Table 4. Summary of External Data Sources

Description	Data Source	Date
Animals per County ($ANIM_{hi}$)	Pennsylvania Agricultural Statistics	1992
Animal Manure Production	Sweeten	1991
Average Animal Liveweight	Sweeten	1991
Nutrients per Ton of Waste	Ressler	1992
Acres of Crops per County	Pennsylvania Agricultural Statistics	1992
Crop Nutrient Removal Rates	Penn. State University	1992
Commercial Fertilizer Sales	Pennsylvania Department of Agriculture	1993
Commercial Fertilizer Nutrient Content	FAO	1991
Fertilizer Prices Paid by Farmers (F_k)	The Fertilizer Institute	1993
Waste Transport Costs (T_{hij})	Quotations from Shippers and from Lancaster Ext. Service	1994
Waste Composting Costs (C_h)	Northeast Regional Agricultural Engineering Service	1992

Waste Flows

The flows of uncomposted broiler and layer wastes that are transported intercounty are presented in Tables 5 and 6, respectively, and illustrated in Figure 2. Flows are out of Lancaster and Lebanon (the two counties with excess phosphate) to the neighboring counties of Dauphin, Berks, Chester, and York. The flows of broiler and layer wastes to other counties are zero, as are the flows of other waste types. There are no intercounty transfers of composted wastes. Figures in parentheses represent the distance, in miles, between the corresponding supply and receiving counties. These results do not indicate that, in isolation, it would be uneconomic to transfer other wastes among counties. Rather they indicate that given the overall distribution of waste production and absorption capacities, these are the flows that would occur in a system in which all players efficiently maximize personal welfare. Further, the results do not indicate that when wastes are to be shipped over long distances that composting may not be cost effective. Rather they indicate that if transported efficiently, wastes could be disposed in a manner whereby no pollution is generated without having to ship wastes over such longer distances.

Table 5. Base Flows: Broilers (Tons)

	Receiving Counties		
Supply County	Dauphin	Berks	Chester
Lancaster		71551.35 (30)	73955.90 (25)
Lebanon	7264.68 (35)	18927.04 (30)	

Table 6. Base Flows: Layers (Tons)

	Receiving Counties	
Supply County	York	Chester
Lancaster	143425.6 (25)	4857.93 (25)

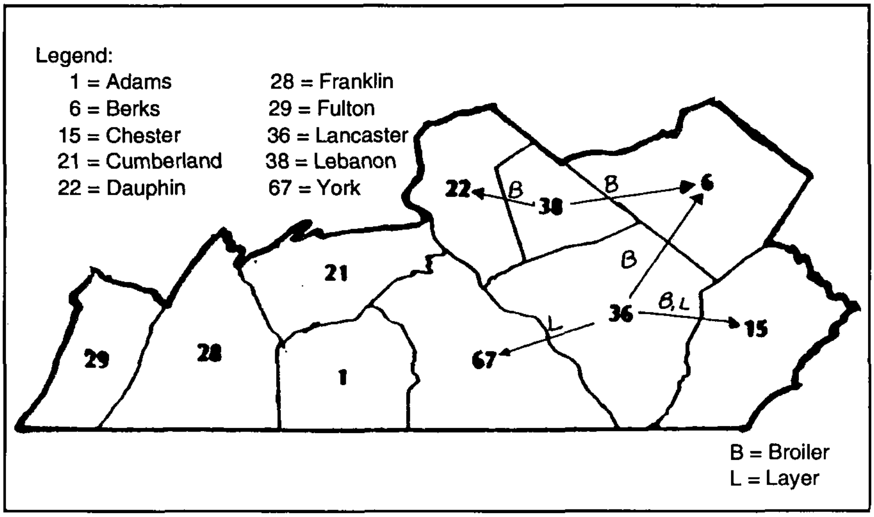

Figure 2. Base model.

Nutrient Levels

No excess nutrient levels were generated for any of the counties in the full-information equilibrium of the base model. Such a result is in direct contrast to the reality of agriculture as a significant contributor of nutrient pollution. The fact that the model shows that in an efficient market no pollution is generated, however, does not mean that there is no nutrient pollution from agriculture in the real world. Clearly there is (although the degree of pollution is far from agreed upon). Rather, the results indicate that whatever pollution occurs is due not to insufficient economic incentives or to an overly extensive agricultural industry. It is more likely due to market inefficiencies such as imperfect information concerning where the markets for wastes are, the relative convenience of purchasing commercial fertilizer, concerns over waste quality control, localized overapplication of nutrients, improper on-farm management practices which allow nutrients to enter surface and groundwaters, and factors related to the seasonality of nutrient demand.

Waste Prices

Tables 7 and 8 present the prices paid for uncomposted and composted wastes, respectively, of the various animal types in the different counties. The prices for the wastes in counties such as Lancaster and Lebanon which have large supplies relative to demand tend to be lower. Counties such as Dauphin, Adams, Cumberland, Franklin, and Fulton, which have excess demand, have higher prices. The values derive from the wastes' relative nutrient values and the cost of transportation. In general it is believed that these provide a fair representation of the wastes' true market value.[3] Field work indicates that broiler manure generally sells for \$24 and \$28 per ton. The results of the model thus slightly underestimate its value.

Since the composted waste prices are based solely on the nutrient values of the wastes, they probably underestimate the true market potential. In most cases carbon-based organic matter is added to manures to obtain the necessary carbon:nitrogen ratio for proper composting. The organic matter provides extra benefits in terms of soil conditioning which increases the porosity of the soil and thus its water retention capacity. Estimates of composted broiler manure being worth \$50/ton to \$150/ton, prices which far exceed its value as a nutrient source, indicate that its value as a soil enhancer may in fact be considerable.

[3] The exception here is swine mature. For purposes of consistency and simplicity, the values used in the model are for solid manure. Due to the waste handling and collection processes generally used, however, swine manure is typically shipped as a liquid waste. Since the addition of water substantially dilutes the nutrient value and increases the weight of the waste, the value of the waste in this form is significantly reduced. The actual value of liquid swine manure, when the additional problems related to odors and vectors are included, is probably negligible and quite possibly negative.

Table 7. Price of Uncomposted Waste for Base Scenario ($/Ton)

County	Dairy	Cattle	Swine	Sheep	Layers	Broilers
Dauphin	3.11	4.15	7.10	4.64	15.14	19.31
Adams	3.11	4.15	7.10	4.64	15.14	19.31
Cumberland	3.11	4.15	7.10	4.64	15.14	19.31
Franklin	3.11	4.15	7.10	4.64	15.14	19.31
Fulton	3.11	4.15	7.10	4.64	15.14	19.32
York	2.98	3.99	6.70	4.55	14.07	18.11
Berks	3.05	4.07	6.90	4.60	14.60	18.71
Chester	2.98	3.99	6.70	4.55	14.07	18.11
Lancaster	2.62	3.53	5.55	4.29	11.06	14.72
Lebanon	2.66	3.58	5.68	4.32	11.40	15.10

Table 8. Price of Composted Waste for Base Scenario
($/Ton of Compost)

County	Dairy	Cattle	Swine	Sheep	Layers	Broilers
Dauphin	5.86	7.60	13.12	8.14	28.38	35.58
Adams	5.86	7.60	13.12	8.14	28.38	35.58
Cumberland	5.86	7.60	13.12	8.14	28.38	35.58
Franklin	5.86	7.60	13.12	8.14	28.38	35.58
Fulton	5.86	7.60	13.12	8.14	28.38	35.58
York	5.42	7.26	12.30	7.96	26.24	33.18
Berks	5.54	7.42	12.70	8.06	27.32	34.38
Chester	5.42	7.26	12.30	7.96	26.24	33.18
Lancaster	4.70	6.34	10.00	7.44	20.22	26.40
Lebanon	4.78	6.44	10.26	7.50	20.90	27.18

Sensitivity to Commercial Fertilizer Prices

In order to determine the degree to which the results of the model were sensitive to the input prices of commercial fertilizers, a series of runs was made in which those prices were varied between 25 percent and 200 percent of the actual price, at intervals of 25 percent. The results were examined to determine the effects such price changes have on the output of the model in terms of the amount of excess nutrients produced, waste flows, and waste prices. Table 9 shows the effects of the fertilizer price changes on the amount of excess phosphate produced

Table 9. Excess Phosphate

Price Factor (%)	Excess Phosphate (Tons)
25	8235.26
50	0
75	0
100	0
125	0
150	0
175	0
200	0

by the system. No excess nitrogen or potash are generated in any scenario. No excess phosphate was generated until the fertilizer prices were reduced to 25 percent of their actual values. The reason that pollution begins to occur at the lower prices is that the nutrients become so cheap that it is no longer cost effective to transfer wastes from surplus to deficit areas. The fact, however, that the prices must be reduced to 25 percent of their actual value in order for the full information system to generate pollution indicates that within the likely range of fertilizer price fluctuations the results of the model in terms of excess nutrient production are insensitive to such fluctuations.

Sensitivity to Nutrient Absorption Capacities

As the nutrient absorption capacities of the counties may vary from year to year based on the amount and type of crops planted, as well as stochastic variables such as weather conditions, and as such variations may affect the results of the model, a series of runs was made adjusting the absorption capacity to a given percentage of the base level. Runs were made over a range of absorption capacities from 50 percent to 150 percent of the base level, at intervals of 10 percent. The results of these runs are presented below in terms of waste flows and excess nutrient levels.

Waste flows under the selected absorption capacity scenarios are shown graphically in Figures 3 and 4. As can be seen, the lower the absorption capacity, the more waste transactions occur. The transactions also occur over greater distances. This is due to the fact that the absorption capacities of other counties besides Lancaster and Lebanon are no longer sufficient to handle their respective livestock productions, or their absorption capacity is reduced so as to be able to handle less waste from counties with excess nutrients. For all scenarios, only uncomposted broiler and layer wastes are transported.

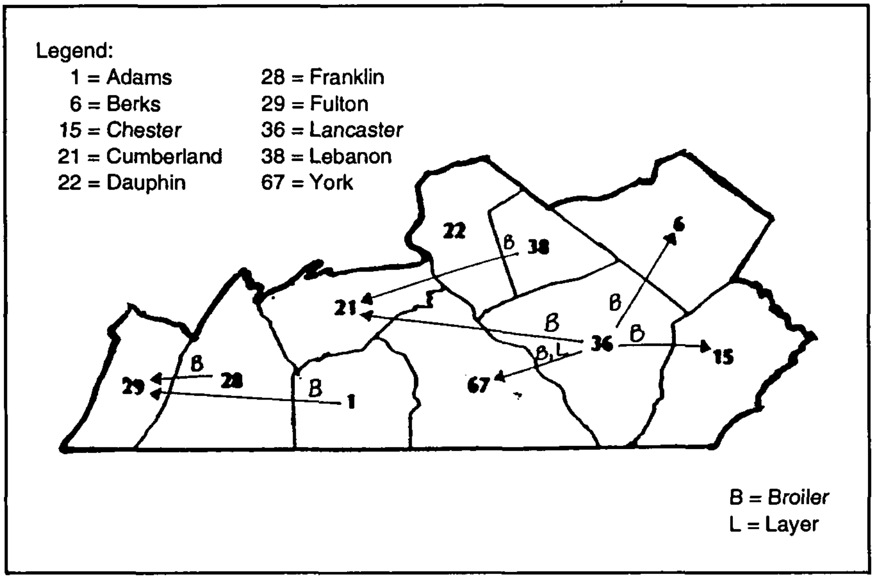

Figure 3. Absorption capacity = 50%.

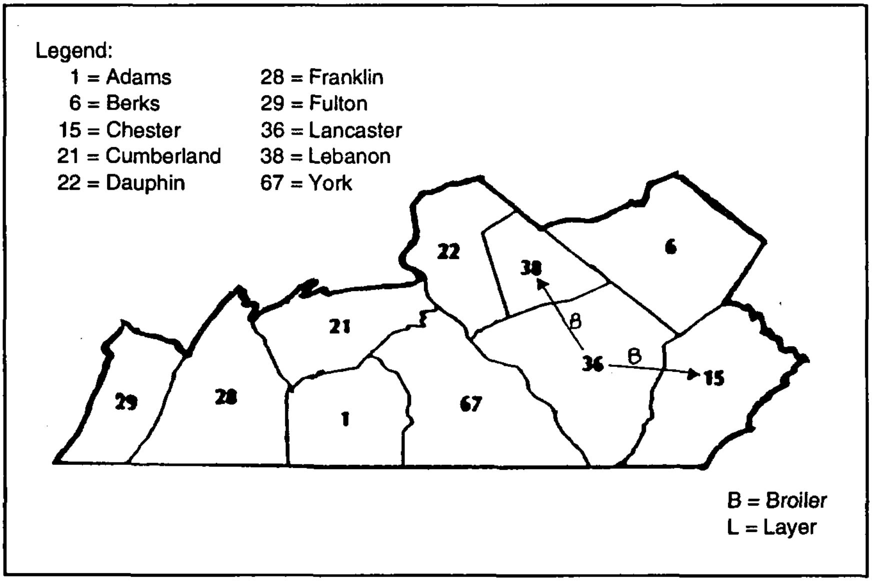

Figure 4. Absorption capacity = 150%.

Table 10. Excess Nutrient Levels

	Excess Nutrients		
Absorption Factor (%)	Nitrogen	Phosphate	Potash
50	0	14242.63	789.08
60	0	10112.56	0
70	0	6612.71	0
80	0	2627.22	0
90	0	0	0
100	0	0	0
110	0	0	0
120	0	0	0
130	0	0	0
140	0	0	0
150	0	0	0

Table 10 presents the excess amount of each nutrient for the whole system, over the range of absorption capacity scenarios. The results show that only when the absorption capacity is reduced to 80 percent of the base scenario is the system unable to absorb all the nutrients produced. At that point, excess phosphate occurs. Only at the 50 percent scenario does an excess of potash occur. Even when the absorption capacity of the system is reduced to 50 percent of the base value, there is no excess nitrogen generated in the system.

Sensitivity to Livestock Production Levels

Livestock production in the Lancaster region has grown considerably in recent decades.[4] Accordingly, questions arise as to the degree to which changes in livestock production levels affect the results of the model. To investigate these questions, the model was run under different livestock production scenarios, ranging between 50 percent and 200 percent of current production, at intervals of 10 percent.

Waste flows under selected livestock production scenarios are shown graphically in Figures 5, 6, and 7. Up to the livestock production level of 160 percent, the quantity and distance of intercounty waste transfers increase with increasing production. This is because there is more excess waste to be disposed. Beyond

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[4] According to Young et al. [5], between 1970 and 1980, dairy cattle numbers in Lancaster County rose 40 percent, hogs 209 percent, broiler chickens 134 percent, and layer chickens 143 percent.

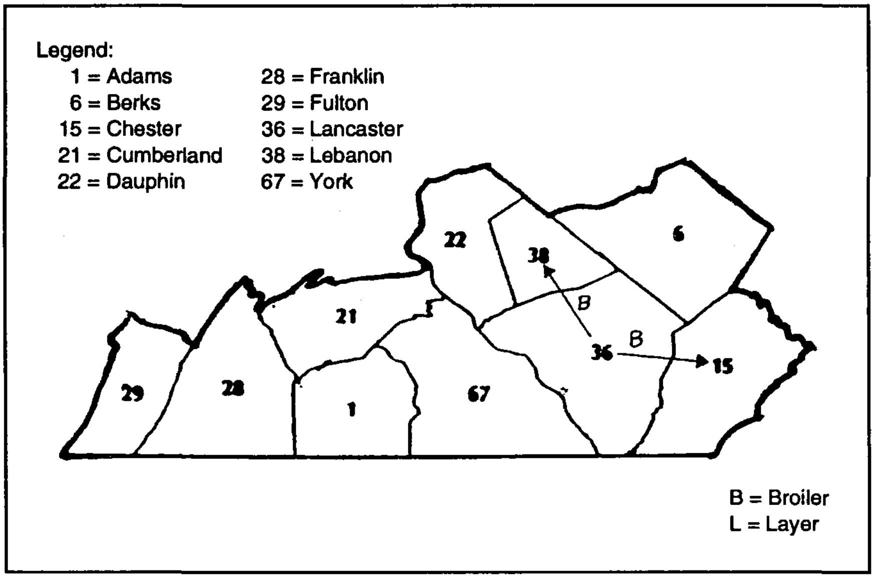

Figure 5. Livestock production = 60%.

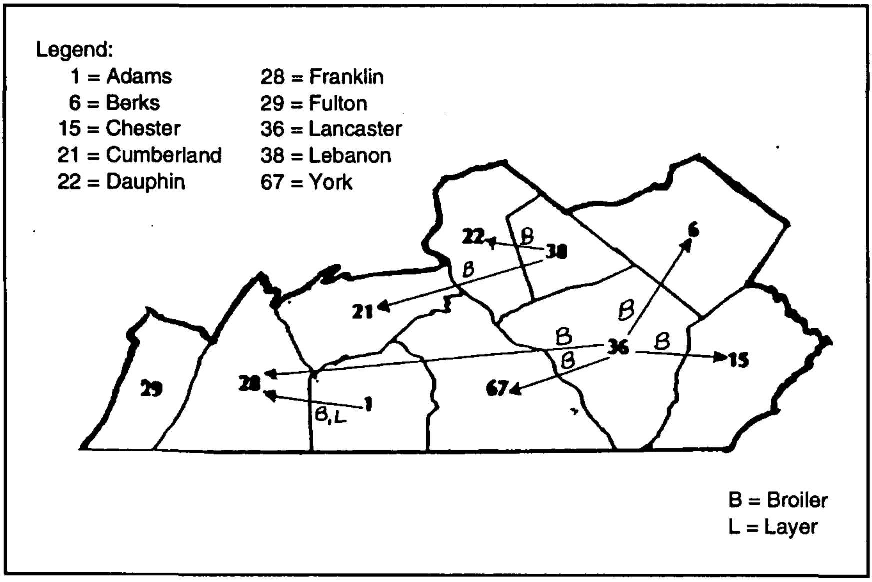

Figure 6. Livestock production = 150%.

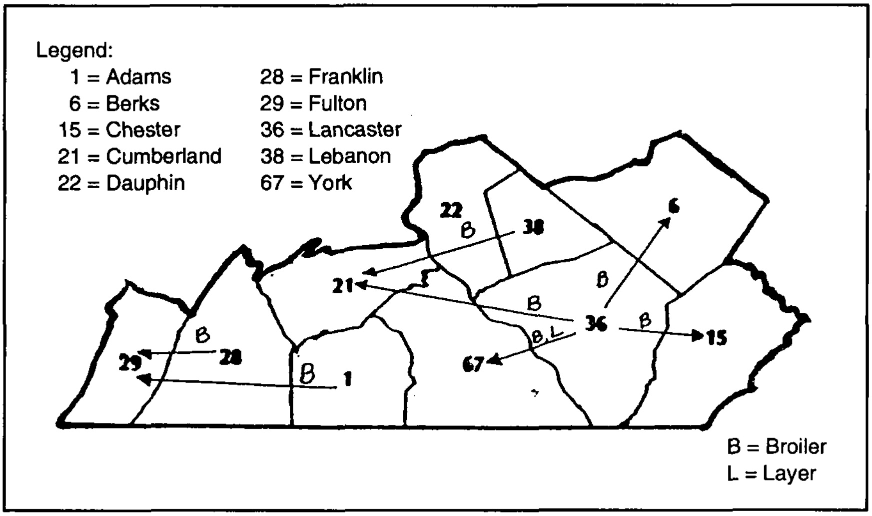

Figure 7. Livestock production = 200%.

160 percent, however, the trend reverses, reflecting the fact that counties which initially had excess nutrient capacity began to become saturated.

As shown in Table 11, no excess nutrients occur in the system until livestock production reaches 120 percent of the base level, at which point excess phosphate is generated. As livestock production is increased the excess phosphate value also increases. No excess potash is generated until livestock production reaches 200 percent. Even with livestock production double its current level, no excess nitrogen would be generated in a fully efficient economy.

Commercial nutrient purchases are shown in Table 12. For all nutrients, as livestock production increases, the amount of commercial fertilizer purchased is reduced. Commercial nitrogen and potash are purchased in all scenarios. Commercial phosphate is purchased until livestock production is 150 percent of current levels. Accordingly, for scenarios between 120 percent and 150 percent, commercial phosphate is being purchased even though excess phosphate occurs in the system. Likewise, for the 200 percent scenario, commercial potash is purchased even though excess potash occurs in the system. This is due to the inefficiencies caused by the fixed ratios of nutrients in the wastes.

4.2 Information Costs

Since the results of the base model indicated that agricultural nutrient pollution was due not to insufficient market incentives, but instead to informational and other inefficiencies, an attempt was made to estimate the extent of those

Table 11. Excess Nutrient Levels for Livestock Production Scenarios

Livestock Production Factor (%)	Excess Nutrients		
	Nitrogen	Phosphate	Potash
50	0	0	0
60	0	0	0
70	0	0	0
80	0	0	0
90	0	0	0
100	0	0	0
110	0	0	0
120	0	1558.48	0
130	0	5009.58	0
140	0	8460.69	0
150	0	11911.80	0
160	0	14528.08	0
170	0	18017.37	0
180	0	21506.67	0
190	0	24995.97	0
200	0	28485.26	1578.17

inefficiencies. To do so, an information cost term (INFOCOST) was introduced into the model. With the information term (INFOCOST) included the objective function of each player becomes:

$$\begin{gathered}\mathrm{MAX}\ (\Sigma_{hj}(\mathrm{PNON}_{hj}-\mathrm{TNON}_{hij}-\mathrm{INFOCOST})\mathrm{SNON}_{hij} + \\ \Sigma_{hj}(\mathrm{PCOM}_{hj}-\mathrm{C}_{h}-\mathrm{TCOM}_{hij}-\mathrm{INFOCOST})\mathrm{SCOM}_{hij} - \Sigma_{k}\mathrm{F}_{k}\mathrm{Z}_{ik} - \\ \Sigma_{h}\mathrm{PNON}_{hi}\mathrm{DNON}_{hi} - \Sigma_{h}\mathrm{PCOM}_{hi}\mathrm{DCOM}_{hi})\end{gathered}$$

where INFOCOST is an additional per unit[5] cost placed on suppliers in trying to dispose of their waste off-site. The constraints and market-clearing conditions remain the same as in the base scenario; the supply first order conditions become

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[5] The per unit assumption may not be completely accurate. On the one hand, once a potential market for wastes is found, the per unit information costs of supplying additional wastes to that market go to zero. However, once initial markets are used up, the marginal information costs of finding further markets may increase. It is unclear, therefore, what the true shape of this information cost curve is. For purposes of analytical simplicity, and due to the fact that the INFOCOST term is being used simply as a crude proxy to determine the order of magnitude of the inefficiencies in the market, the per unit assumption is believed to be reasonable.

Table 12. Commercial Nutrient Purchases for Livestock Production Scenarios

Livestock Production Factor (%)	Commercial Nutrients Purchased		
	Nitrogen	Phosphate	Potash
50	100018.40	23854.19	65589.33
60	96951.52	20364.89	62261.30
70	93884.65	16875.59	58933.28
80	90817.78	13386.30	55605.26
90	87750.91	9897.00	52277.23
100	84684.03	6407.70	48949.21
110	81617.16	2918.41	45621.18
120	78550.29	987.59	42293.16
130	75483.42	949.40	38965.13
140	72416.55	911.21	35637.11
150	69349.68	873.02	32309.08
160	66282.80	0	28981.06
170	63215.93	0	25653.04
180	60149.06	0	22325.01
190	57082.19	0	18996.99
200	54015.32	0	17247.13

$$\mathrm{PNON}_{hj} - \mathrm{TNON}_{hij} - \mathrm{INFOCOST} - \Sigma_m \mathrm{NUTNON}_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \perp \mathrm{SNON}_{hij} \geq 0$$

and

$$\mathrm{PCOM}_{hj} - \mathrm{TCOM}_{hij} - C_h - \mathrm{INFOCOST} - \Sigma_m \mathrm{NUTCOM}_{hm}\Theta_{im} - \Psi_{hi} \leq 0 \\ \perp \mathrm{SCOM}_{hij} \geq 0$$

The INFOCOST term was gradually increased to determine the point at which pollution began to be generated. The results of the analysis are presented in Table 13. The case where INFOCOST = 0 represents the base scenario. As the results indicate, no excess nutrients are generated until the information cost equals \$5. Pollution does not stabilize at its maximum until the information cost equals \$8. Taken as a rough guide, and assuming that a certain amount of pollution is generated in reality, these results indicate that the inefficiencies in the actual system above the purely efficient market are between \$5 and \$8 per ton. Since broiler manure is worth roughly \$25/ton in reality (or about \$19/ton according to the model) these costs are substantial, representing between 20 and 25 percent of the value of the waste. For dairy and cattle wastes, these costs may actually exceed the value of the waste.

Table 13. Information Cost Nutrient Levels (Tons)

	Excess Nutrients			Commercial Nutrients Purchased		
INFOCOST	Nitrogen	Phosphate	Potash	Nitrogen	Phosphate	Potash
0	0	0	0	84684	6407	48949
1	0	0	0	84684	6407	48949
2	0	0	0	84684	6407	48949
3	0	0	0	84684	6407	48949
4	0	0	0	84684	6407	48949
5	0	197.24	0	84684	6604.9	48949
6	0	3573.63	0	84684	9981.3	48949
7	0	4284.74	0	84684	10692.4	48949
8	0	8235.26	0	84684	14642.9	54949
9	0	8235.26	0	84684	14642.9	54949
10	0	8235.26	0	84684	14642.9	54949

It is important that these inefficiency costs generated by the model be viewed only as broad indicators rather than actual values. Nevertheless, it is believed that they provide a reasonable approximation of at least the order of magnitude of the problem. These inefficiencies have a considerable impact on the market, and thus must be incorporated in any attempt to promote waste transfers as a means to reduce nutrient pollution.

4.3 Transport Subsidy

Since in the base model there are already no excess nutrients generated, providing a transport subsidy to induce greater waste transport to reduce pollution has no effect on the model. Runs with transport subsidies were made with high information costs included in the model to see the effects of the subsidies in such cases. The results of those runs are presented in Table 14 in terms of the excess phosphate generated. Excess nitrogen and potash were zero for all cases. As can be seen, the results were extremely sensitive to the INFOCOST value used in the model. While the transport subsidy has the effect of increasing the distance wastes can economically be shipped, and of reducing the transport cost over a given distance, such effects are overshadowed by the informational inefficiencies in the market.

Tables 15 and 16 show the effects of the transport subsidy on the various waste prices in Fulton and Lancaster Counties, respectively, for the case where information costs are assumed to be $8/ton. Fulton generally has the highest waste prices of all counties, while Lancaster has the lowest. In both cases, the prices of dairy,

Table 14. Excess Phosphate under Transport Subsidy Scenarios (Tons)

Transport Subsidy ($/Ton)	INFOCOST					
	5	6	7	8	9	10
0	197.24	3573.63	4284.74	8235.26	8235.26	8235.26
1	0	1942.62	4284.74	8235.26	8235.26	8235.26
2	0	1942.62	3573.63	8235.26	8235.26	8235.26
3	0	197.24	3573.63	8235.26	8235.26	8235.26
4	0	0	3573.63	4284.74	8235.26	8235.26
5	0	0	1942.62	4284.74	8235.26	8235.26
6	0	0	197.24	3573.63	8235.26	8235.26
7	0	0	0	3573.63	8235.26	8235.26
8	0	0	0	3573.63	4284.74	8235.26
9	0	0	0	197.24	3573.63	8235.26
10	0	0	0	0	3573.63	8235.26
11	0	0	0	0	3573.63	8235.26
12	0	0	0	0	3573.63	3573.63

Table 15. Excess Phosphate under Off-Site Subsidy Scenarios (Tons)

Off-Site Subsidy ($/Ton)	INFOCOST ($/Ton)			
	6	7	8	9
0	3573.63	4284.74	8235.26	8235.26
1	197.24	3573.63	4284.74	8235.26
2	0	197.24	3573.63	4284.74
3	0	0	197.24	3573.63
4	0	0	0	197.24
5	0	0	0	0

cattle, and sheep are virtually unaffected by the subsidy level. In Fulton the prices of layer and broiler wastes tend to decrease with the increased subsidy. This reflects the fact that the subsidy reduces the cost of transport to the area. For Lancaster, however, the increased subsidy increases the price of the broiler waste because the increased demand from other countries has increased the value of the waste. The price of layer wastes in Lancaster is in general unaffected by the subsidy level.

Table 16. Waste Prices Under Transport Subsidy Scenarios
(Fulton County) INFOCOST = $8/Ton

Transport Subsidy ($/Ton)	Uncomposted Waste Type ($/Ton)					
	Dairy	Cattle	Swine	Sheep	Layers	Broilers
0	3.11	4.15	7.10	4.64	23.14	26.85
1	3.11	4.15	7.10	4.64	23.14	26.85
2	3.11	4.15	15.10	4.64	23.14	27.25
3	3.11	4.15	15.10	4.64	23.14	26.25
4	3.11	4.15	15.10	4.64	22.21	25.25
5	3.11	4.15	15.10	4.64	22.21	24.25
6	3.11	4.15	7.10	4.64	20.21	23.51
7	3.11	4.15	7.10	4.64	19.21	22.81
8	3.11	4.15	7.10	4.64	18.21	22.11
9	3.11	4.15	7.10	4.64	15.14	20.76
10	3.11	4.15	7.10	4.64	16.46	20.61

4.4 Off-Site Subsidy

Within the model, the off-site subsidy has the effect of exactly canceling the information costs. That is, while the information costs represent a per ton cost of transferring wastes from an excess county, the off-site subsidy is a per ton incentive for such transfers. While such a subsidy does not reduce information costs, it does provide incentives where they may be most effective: directly to farmers to seek external markets for their wastes. The results of selected off-site subsidy scenarios in terms of excess phosphate generation are presented in Table 17. The results are shown over a range of subsidy values from 0 to 5 $/ton of waste, and a range of information costs from 6 to 9 $/ton. Excess nitrogen and potash levels were zero for all scenarios. As can be seen in Table 17, a $1 increase in the subsidy directly offsets a $1 increase in information costs in terms of the amount of pollution generated.

4.5 Compost Subsidy

Tables 18 and 19 show the transfers of uncomposted and composted broiler wastes under the various compost subsidy model scenarios, respectively. Table 20 shows the flows of uncomposted and composted layer wastes. All other waste flows are zero for all scenarios. As the results indicate, up to and including the $3.5 per ton composting subsidy only uncomposted wastes are transferred. At the $4 per ton subsidy composted broiler manure begins to be shipped from Lebanon

Table 17. Waste Prices Under Transport Subsidy Scenarios (Lancaster County) INFOCOST = $8/Ton

Transport Subsidy ($/Ton)	Uncomposted Waste Type ($/Ton)					
	Dairy	Cattle	Swine	Sheep	Layers	Broilers
0	2.04	2.78	3.70	3.87	14.21	17.25
1	2.04	2.78	3.70	3.87	14.21	17.25
2	2.04	2.78	3.70	3.87	14.21	17.25
3	2.04	2.78	3.70	3.87	14.21	17.25
4	2.04	2.78	3.70	3.87	14.21	17.31
5	2.04	2.78	3.70	3.87	14.21	17.56
6	2.04	2.78	3.70	3.87	14.21	17.81
7	2.04	2.78	3.70	3.87	14.21	18.06
8	2.04	2.78	3.70	3.87	14.21	18.31
9	2.04	2.78	3.70	3.87	6.21	18.36
10	2.07	2.82	11.79	3.89	14.48	18.61

to Dauphin. At the $4.5 subsidy all broiler shipments are composted as are layer transfers from Lancaster to York. At the $5 subsidy, all waste shipments are composted. Since the assume cost of composting in the model is $6/ton, these subsidy values are very large and would likely be impracticable in the real setting. Their large size is due primarily to the fact that in the model wastes are only transferred over relatively short distances. Since, in reality, some wastes (primarily poultry wastes) are being shipped over longer distances, compost subsidies may be appropriate and may increase waste flows with even small subsidies. Separate analyses have shown that, as a rough guide, composting becomes cost-effective when wastes are to be shipped 100 miles or greater [20].

4.6 Excess Nutrient Tax

Since there was no pollution in the base model, inclusion of an excess nutrient tax had no effect. A series of runs was made, however, over a matrix of tax levels and information costs. Taxes ranged from 0 to 220 $/ton of phosphate. Information costs were varied from 5 to 10 $/ton of waste. The results are presented in Table 21. (Since the model shows 0 nitrogen and potash being generated under all scenarios, similar analyses were not performed for those nutrients.) As the results indicate, the effects of the tax are highly sensitive to the amount of information costs assumed to exist. As information costs are increased, the tax level required to maintain the same pollution level also increases. As a general rule, it is found

Table 18. Uncomposted Broiler Waste Transfers under Compost Subsidy Scenarios (Tons)

Subsidy ($/Ton)	Lebanon to		Lancaster to		
	Dauphin	Berks	Berks	Chester	York
0	7264.68	18927.04	71551.35	73955.90	0
1	7264.68	18927.04	71551.35	73955.90	0
2	7264.68	18927.04	71551.35	0	73955.90
3	7264.68	18927.04	71551.35	73955.90	0
3.5	7264.68	18927.04	71551.35	73955.90	0
4	0	18927.04	71551.35	73955.90	0
4.5	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0

Table 19. Composted Broiler Waste Transfers under Compost Subsidy Scenarios[a] (Tons)

Subsidy ($/Ton)	Lebanon to		Lancaster to		
	Dauphin	Berks	Berks	Chester	York
0	0	0	0	0	0
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
3.5	0	0	0	0	0
4	7264.68	0	0	0	0
4.5	7264.68	18927.04	71551.35	0	73955.90
5	7264.68	18927.04	71551.35	73955.90	0
6	7264.68	18927.04	71551.35	0	73955.90

[a] The composed quantities are in terms of the amount of raw manure that goes into the compost, not the weight of the compost itself.

Table 20. Layer Waste Transfers under Compost Subsidy Scenarios[a] (Tons)

Subsidy ($/Ton)	Uncomposted Lancaster to		Composted Lancaster to	
	York	Chesters	York	Chester
0	143425.60	4857.93	0	0
1	143425.60	4857.93	0	0
2	60110.15	88273.39	0	0
3	143425.60	4857.93	0	0
3.5	143425.60	4857.93	0	0
4	143425.60	4857.93	0	0
4.5	60110.15	0	0	88273.39
5	0	0	143425.60	4857.93
6	0	0	60110.15	88273.39

[a] The composed quantities are in terms of the amount of raw manure that goes into the compost, not the weight of the compost itself.

Table 21. Phosphate Pollution Levels under Excess Nutrient Tax Scenarios (Tons)

Tax Level ($/Ton of Phos.)	Information Cost ($/Ton of Waste)					
	5	6	7	8	9	10
0	197.24	3573.63	4284.74	8235.26	8235.26	8235.26
20	0	1942.62	3573.63	8235.26	8235.26	8235.26
40	0	197.24	3573.63	4284.74	8235.26	8235.26
60	0	0	1942.62	3573.63	8235.26	8235.26
80	0	0	197.24	3573.63	4284.74	8235.26
100	0	0	0	1942.62	3573.63	8235.26
120	0	0	0	197.24	3573.63	4284.74
140	0	0	0	0	1942.62	3573.63
160	0	0	0	0	197.62	3573.63
180	0	0	0	0	0	1942.62
200	0	0	0	0	0	197.24
220	0	0	0	0	0	0

that roughly a $40/ton of phosphate tax is required to offset a $1/ton of waste increase in the information cost. For any given level of information cost, it requires a tax of about $120/ton of phosphate to reduce pollution from the point at which pollution reaches its maximum level to a point of zero pollution

5.0 CONCLUSIONS

The results of the model concerning cost and pollution abatement of the market-based policy alternatives were to some degree obscured by the high degree of informational and other inefficiencies that were found to exist in the market. Since no pollution was generated in the base model, incorporation of the various policies to reduce pollution had no effect. Scenarios which incorporated an information cost term allowed the study of the various policies in a more realistic setting. For all market mechanisms, at a given information cost level, increasing the tax or subsidy reduced the amount of pollution generated. For all subsidy scenarios, increasing the subsidy increased the associated government expenditures due both to the increased per unit subsidy and the increased volume of waste transfers. For the tax scenario, government revenues increased with the tax rate up to a certain point and then began to decrease. This was because at first the per unit tax increased at a greater rate than the excess nutrients were reduced, but at the higher tax rates the reverse was true. The information cost term was only a crude proxy for the actual inefficiencies in the market, however, and the results of the models for all of the market incentives were highly sensitive to the amount of inefficiency assumed to exist in the market.

Under all scenarios, intercounty waste transfers were either of broiler or layer wastes. Only in cases with high ($4/ton or more) composting subsidies were wastes composted. [A transfer of composted waste also occurred when livestock production was increased to 160 percent of its base value. At that point, composted broiler waste was shipped from Lancaster to Fulton County.] Otherwise all intercounty transfers were of uncomposted waste. As would be expected, implementation of the various market incentives tended to increase both the amount and distance of waste transfers in the system. The amount of increase depended on the type of incentive, the size of the incentive, and the amount of inefficiency assumed in the system. Waste flows were also sensitive to the levels of livestock production and absorption capacity used in the model. In general waste transfers increased as absorption capacity was reduced. They increased with livestock production until a level of 160 percent of the base value. At that point the deficit counties started to become saturated and unable to absorb excess wastes from other counties.

As a general rule, waste prices were lowest in Lancaster and Lebanon Counties, where there was excess phosphate. In the base model, the minimum prices for broiler and layer wastes (which occurred in Lancaster) were $14.72 and $11.06 per ton, respectively. Fulton County consistently had the highest prices due to its being farthest away from Lancaster and Lebanon. The values for broiler and layer wastes in Fulton County in the base model were $19.32 and $15.14 per ton, respectively. In several scenarios other counties had waste prices equivalent to those in Fulton. Otherwise, waste prices fell somewhere between the two extremes.

With regard to the various market incentives investigated, the off-site subsidy appears to have the greatest potential to promote inter-farm waste transfers and thus to reduce nutrient pollution. The primary advantage of the off-site subsidy is that it is aimed directly at encouraging farmers to seek external markets for their wastes. As with most subsidy programs, the implementation of the off-site program is relatively simple. Developing the necessary government funding for such a subsidy may be difficult, however. A full discussion of the implementational factors related to each of the policy alternatives is provided in Norman [20].

Although the transport subsidy provides some incentive at the margin, it does not directly address the underlying inefficiencies in the market. Further, the analysis showed that complete and efficient waste disposal can at least theoretically be achieved within relatively short transport distances (no greater than 35 miles in the base scenario) that are well within the cost-effective range for farmers (especially for broiler and layer wastes). Because of these factors the transport subsidy is not recommended as an ideal policy. It makes more sense to try to identify and develop the markets that exist within the already cost-effective shipping range. Developing markets for backhauling would also reduce the cost of transport.

Within the model, waste composting does not become cost-effective from the standpoint of reduced transport costs until composting costs are subsidized by at least 65 percent. This was due to the fact that in the model wastes are only transferred over relatively short distances. Since, in reality, some wastes (primarily poultry wastes) are being shipped over longer distances, compost subsidies may be appropriate and may increase waste flows with even small subsidies.

The excess nutrient tax would generate a marginal economic incentive for farmers to reduce pollution. The extent of that incentive depends not only on the size of the tax, but also on the degree of inefficiency in the market. The tax would only effect waste transfers to the extent those with excess wastes can find markets for them. In addition, the tax has implementational difficulties associated with it that may make it undesirable. A tax that is focused solely on farmers would face strong opposition from the agriculture lobby. The tax would require a considerable informational, monitoring, and enforcement bureaucracy in order to assure compliance. Finally, the nutrient limits are to some degree arbitrary and do not account for stochastic factors such as weather conditions. Due to these factors, the excess nutrient tax is not recommended as a practical option for reducing nutrient pollution.

Finally, due to the high degree of inefficiency that was found to exist in the market, it is believed that, despite their theoretical appeal, market mechanisms may not be the most effective policy for reducing nonpoint source nutrient pollution. An alternative approach, based on reducing informational inefficiencies, appears to be warranted. Such an approach may include manure marketing surveys to identify and connect potential suppliers and demanders of wastes, education concerning the importance of nutrient management, and the teaching of proper management practices to reduce nutrient pollution. Such policies are aimed at assisting farmers to take advantage of opportunities that are in the farmers' best interest. They do not require the development of a regulatory infrastructure, and can be carried out by existing extension service offices.

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Direct reprint requests to:

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