Multiple Environmental Externalities and Manure Management Policy

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Abstract

Livestock waste pollutes multiple environmental media along multiple dimensions. This study explores the economic and environmental implications of single-medium and coordinated multi-media policies for reducing manure-related externalities, with particular attention paid to tradeoffs that occur when policies designed to correct an externality in one medium ignore externalities in other media.

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1. Introduction

One of the difficulties in addressing the environmental problems associated with livestock waste is that manure can pollute multiple media (air, water, and soil) along multiple dimensions. Air quality concerns related to manure include odorous gases (ammonia and hydrogen sulfide), particulate material (by-products of ammonia), and greenhouse gases (methane and nitrous oxide). Water pollutants from manure include nitrogen, phosphorus, antibiotics, and pathogens. The theory of the second best demonstrates that the correction of a single market distortion without simultaneously correcting other sources of market failure can lead to Pareto-inferior resource allocations (Lipsey and Lancaster, 1956). The theory implies that policies to address pollution in a single medium could worsen pollution in other media, resulting in lower societal welfare. This paper considers the economic and environmental implications of regulating both water and air nitrogen emissions under single-environmental medium and coordinated multi-environmental media policies. Particular attention is paid to tradeoffs that occur when policies are designed to correct an externality in one medium without considering externalities in other media.

The Environmental Protection Agency has recently introduced regulations for concentrated animal feeding operations (CAFOs) under the Clean Water Act. These regulations require, among other things, that CAFOs applying manure to land meet nutrient application standards defined by a Comprehensive Nutrient Management Plan (USEPA, 2003). To help defray the costs of the meeting the new regulations, producers can apply for financial assistance from the USDA’s Environmental Quality Incentive Program (EQIP). Producers can receive up to $450,000 per farm during 2002-2007 to help them develop and implement a nutrient management plan, and to transfer and apply manure to land in an approved manner (USDA, NRCS, 1999; Ribaudo and Cattaneo, 2004).

Neither State nor Federal governments currently regulate nitrogen air emissions from livestock production. However, ammonia nitrogen emissions could conceivably be regulated under the PM2.5 particulate standard of Clean Air Act, since ammonia is a precursor for ammonium particles, a source of haze (NRC, 2003). Animal Feeding Operations are the largest source of ammonia emissions in the U.S. The PM2.5 standard has withstood court challenges and will go into effect December 2005.

Some past research has considered the effect of livestock production across multiple environmental media. Innes (2000) develops a spatial model of regional livestock production and three associated externalities: spills from animal waste stores, nutrient runoff from excess application of manure to croplands, and ambient pollution. Innes models the regulation of waste storage lagoon 'quality', the number of animals in the production facility, or the distance of facilities to one another. An important premise of Innes' analysis is that regulators are unable to monitor environmental outcomes, including manure application rates. In fact, recently implemented EPA CAFO regulations are predicated on verifiable nutrient application plans.

Feinerman, Bosch, and Pease (2003) extend Innes' analysis by evaluating state regulatory standards for manure spreading in Maryland and Virginia. Their approach uses a derived manure demand function to simulate the effects of manure spreading regulations on welfare and excess nutrient loading in soil. In this study, we extend the scope of past analyses to consider current Federal manure spreading regulations and potential Federal air emission regulations. Specifically, we assess the environmental and economic implications of: 1) nitrogen land application restrictions consistent with recently adopted EPA requirements for CAFOs under the Clean Water Act; 2) EQIP payments available to CAFOs to mitigate costs of CAFO regulations; 3) hypothetical air quality (PM2.5) restrictions for CAFOs under the Clean Air Act; and 4) joint manure application and PM2.5 restrictions with EQIP payments. We consider the effect of these policies on both water quality via excess soil nutrient applications and on air quality via ammonia emissions from manure storage facilities and land applications.

To assess the impact of these policy alternatives, we construct a positive mathematical programming model where producers maximize profits subject to resource and regulatory constraints. In the model, nitrogen enters through the feed ration and is retained by the animals or excreted in manure. Once excreted, the nitrogen may be released into the atmosphere through air emissions or contained in the manure storage and handling facility until it is applied to cropland. Nitrogen enters cropland through commercial and manure fertilizer applications. The crop retains some nitrogen, some is bound in the soil substrate and some is released directly into the environment through air emission and water runoff. Using relationships from the scientific literature, the level of water pollution is derived from the estimated quantity of nutrients applied to the land and air emissions are derived from total animal production and the type of storage and handling technology employed by the animal feeding operation. The model is calibrated with data from the 1998 USDA-ARMS survey of hog operations using positive mathematical programming (Howitt, 1995).

Results demonstrate that policies designed to account for only one environmental externality may have unintended consequences in other environmental media. We find that imposing ammonia nitrogen standards on CAFOs in the absence of nutrient application standards results in an increase in excess nitrogen applied to soil. However, imposing nutrient application standards consistent with 2003 EPA regulations results in negligible changes in air nitrogen emissions. The study also provides information about the costs and responses to farmers of complying with joint air and soil nitrogen standards.

2. Analytic Model

For the policy analysis we construct a hog farm model that captures the essential tradeoffs between air and water emissions. The severity of air and water quality degradation from livestock production depends primarily on how manure is stored and disposed of. The application of manure to fields when nutrients in the manure exceed what crops can absorb has been associated with increased algae production, reduced fish populations and diminished recreational opportunities (USEPA, 1998). Because of the high cost of transporting manure relative to the value of the nutrients contained in the manure, farmers have an incentive to over-apply manure to land located near their livestock facilities. A nutrient application standard can force farms to transport manure a significant distance from the hog facility. Farmers can reduce manure transportation costs under an application standard by reducing the nutrient content of the manure – allowing them to apply more manure per acre. The nutrient content of manure can be reduced by storing it in lagoons before applying it or by surface applying it rather than injecting it.

Ammonia emissions from manure storage facilities and from manure applied to fields may impair air quality downwind, and contribute to soil nutrient loading through atmospheric deposition. Lagoons reduce manure nutrient content through the volatilization of nitrogen in the form of ammonia. Manure lagoons may be covered to reduce ammonia emissions, but this maintains the nitrogen content of the manure. Ammonia nitrogen emissions from fields can be reduced through sub-surface injection of the manure. Manure injected to the soil results in more nitrogen being available to the crops, which reduces the amount of manure that can be applied to a field under a nutrient application standard, increasing the land required to dispose of the manure.

Positive mathematical programming (PMP) is used to calibrate the model to base year data without having to add constraints that cannot be justified by economic theory. PMP takes advantage of the fact that it is easier to collect information about output and input levels at the farm level than information about costs. The observed outputs and inputs levels result from a complicated decision process based in part on a cost function that is known to the farmer but difficult or impossible to observe directly. Some costs – perhaps associated with the environment, risk, or technology – may be hidden to the researcher even when a detailed survey instrument is available. PMP incorporates information about unobservable costs by using a quadratic cost function that approximates the true underlying cost function.

There are three steps to the PMP calibration (Howitt, 1995). In the first step, a constrained linear programming model is used to derive dual values associated with the "calibration constraints". In the second step, the dual values are used to parameterize a calibrated quadratic objective function. In the third step, the calibrated model is used for economic analysis, by imposing environmental policy constraints.

2.1 Linear program to calculate dual values.

In the first step, the linear objective is to maximize total net revenues:

$$(1) \qquad \max_{X1_{ir}} \sum_r \sum_i X1_{ir} \left(P_{ir} - C_{ir}\right),$$

where $X1_{ir}$ is the level of each output *i* in region *r*. The cost of producing each output is $C_{ir} = \sum_j A_{ijr} W_{jr}$, where A_{ijr} is the amount of input *j* required to produce a unit of output and W_{jr} is the input price. The optimization is subject to $j \times r$ resource constraints:

(2) $$\sum_i A_{ijr} X1_{ir} \leq \sum_i A_{ijr} X0_{ir} \text{ , } \forall \; j, r$$

where $X0_{ir}$ is the initial observed activity level, so that $\sum_i A_{ijr} X0_{ir}$ is the initial level of input *j*.

Inputs include land, capital, feeder pigs, feed corn, feed soy, and chemical fertilizer nitrogen. Outputs include hogs, corn, soybeans, and "other crops" (defined as the value of all other crops produced). All three crops can be produced under three fertilization regimes: 1) chemical fertilizer, 2) manure fertilizer surface applied, or 3) manure fertilizer injected into the soil. We use the extension of PMP developed by Röhm and Dabbert (2003) to allow for a greater policy response between crop fertilization regimes than between crops. To do so we define three "variant activities" (chemical fertilizer, manure-spread, and manure-injected) for each crop and impose calibration constraints that distinguish between variant activities and the total activity for each crop. In practice, this approach results in greater substitution between, for example, corn fertilized by spreading manure and corn fertilized by injecting manure, than between corn and "other crop" production.

The calibration constraints for each activity are:

(3) $$X1_{ir} \leq X0_{ir}\left(1+\varepsilon_1\right), \; \forall \; i,r \qquad \text{dual: } \hat{\lambda}_{i,r}$$

where ε_1 is a small perturbation (see Howitt, 1995). Following Röhm and Dabbert, we include three additional calibration constraints corresponding to each set of variant activities. For corn activities, the additional calibration constraint is:

(4) $$\sum_{i \in cv} X1_{ir} \leq \sum_{i \in cv} X0_{ir}\left(1+\varepsilon_2\right), \; \forall \; i,r \qquad \text{dual: } \hat{\lambda}_{corn,r}$$

where *cv* is the set of corn variant activities: *cv* = {corn – chemical fertilizer, corn – spread manure, corn – injected manure}. There are two additional constraints analogous to (4) corresponding to soybean variant activities *sv* and other crops variant activities *ov*.

From the 1998 ARMS survey and other sources, we observe prices P_{ir}, W_{ir}, the output levels $X0_{ir}$, and most of the input-output coefficients A_{ijr} (see appendix for details). It would be desirable to include manure nitrogen as an input. However, we do not observe manure application rates, only the amount of land on which manure is applied.

2.2 Estimate calibrated quadratic cost function

In step 2 we define quadratic total variable costs as $\frac{1}{2}\hat{Q}_{ir}X2_{ir}^2$, where $\hat{Q}_{ir} = \left(\hat{\lambda}_{ir} + \hat{\lambda}_{crop,r} + C_{ir}\right)\big/ X0_{ir}$, $\hat{\lambda}_{ir}$ are the estimated dual values associated with (3) the calibration constraints, and $\hat{\lambda}_{crop,r}$ are the estimated dual values associated with (4) the calibration constraints for each crop activity: *crop* ∈ {*corn, soybean, other*}. Since (4) applies only to crops, $\hat{Q}_{ir} = \left(\hat{\lambda}_{ir} + C_{ir}\right)\big/ X0_{ir}$ for *i=hogs*. The objective in step 2 is to maximize total net revenues:

$$(5) \qquad \max_{X2_{ir}} \sum_r \sum_i P_{ir}X2_{ir} - \frac{1}{2}\hat{Q}_{ir}X2_{ir}^2$$

subject to the resource constraints:

$$(6) \qquad \sum_i A_{ijr}X2_{ir} \le \sum_i A_{ijr}X0_{ir}, \ \forall \ j, r$$

Solution of the non-linear optimization problem defined by (5) and (6) results in the initial output levels $X0_{ir}$.

2.3 Estimate activity levels for policy scenarios using calibrated cost function

Having characterized the farmer's non-linear optimization problem that results in the observed initial values, the final step is to impose policy constraints and compare solutions to the initial values. The policies we consider are the CAFO nitrogen application constraint and a hypothetical ammonia emission constraint. Farms can respond to policy constraints by adjusting input and output levels. Pit storage operations can vary the amount of land on which they inject versus surface-apply manure slurry in order to alter the ammonia emitted to the air and the nutrients available to plants. Lagoon operations can cover their lagoons to reduce air ammonia emissions. EQIP payments enter the farmer's decision problem by reducing costs of abiding by the CAFO rules.[1]

First we incorporate into the optimization a manure transportation cost that depends on the how the manure is stored and handled. Prior to implementation of the CAFO manure application rules, farmers had little incentive to transport manure off-farm, and few did. According to the 1998 survey, fewer than 2% of farms transported manure off farm. The CAFO manure application rules require farmers to apply manure at a rate that plants can absorb. In response to the CAFO rules, farmers without adequate cropland will need to transport some manure off-farm (Ribaudo et al, 2003).

For the policy analysis, the farmer's objective is:

$$(7) \qquad \max_{X3_{ir}, COV_r} \sum_r \sum_i P3_{ir} X3_{ir} - \frac{1}{2}\hat{Q}_{ir} X3_{ir}^2 - (1 - EQIP)MTC_r - CC_r$$

where MTC_r is the cost of transporting manure off-farm, which is a function of technology choices that affect that nutrient availability to the crop – and consequently the amount of land on which the manure must be spread. Farms eligible for EQIP payments receive a share of the manure transportation costs and receive a per acre subsidy for land on which they apply manure at the agronomic rate. *EQIP* is defined as the share of manure transportation costs financed by EQIP. The per-acre EQIP subsidy is expressed as a per-unit subsidy and appears in the optimization as a higher price *P3*. The decision by lagoon farms to cover their lagoon is reflected in the binary choice variable COV_r (1 if covered, 0 otherwise). The cost of covering a lagoon is simply a cost κ per unit of hog output: $CC_r = COV_r \cdot \kappa \cdot X3_{hogs,r}$.

Manure transportation costs depend on the nutrient content of the manure (how it was stored), how it is applied (injected or spread), on the availability of land on which to apply the manure, and on what crops it is applied. Estimates for the transportation costs per hundredweight of hog are based on a transportation cost model proposed by Fleming et al (1998) (see appendix for details). Manure transportation costs equal the quantity of hogs used to produce manure transported off-farm $hogs\_off_r$ multiplied by the manure transportation costs per hundredweight of hog. Manure transportation costs are distinguished for lagoon operations, which may or may not cover their lagoons:

$$(8) \qquad MTC_r = hogs\_off_r \left(COV_r * T_{\text{cov}er,r} + (1 - COV_r) * T_{un\text{cov},r} \right),$$

and for pit storage operations which may inject (versus surface apply) manure into some portion of the land on which manure is applied:

$$(9) \qquad MTC_r = hogs\_off_r \left(INJ_r * T_{inject,r} + (1 - INJ_r) * T_{surf,r} \right),$$

where transportation costs per hundredweight of hog produced $T_{e,r}$ depend on the manure storage and handling technology $e \in$ {covered, uncovered, surface-applied, injected}.

For lagoon operations, COV_r is a binary choice variable. For pit storage operations, INJ_r is the share of manure-applied cropland on which manure is injected:

$$(10) \qquad INJ_r = \sum_{i \in mi} A3_{i,land,r} X3_{i,r} \Big/ \sum_{i \in m} A3_{i,land,r} X3_{ir} \ ,$$

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[1] We assume for this analysis that all CAFOs are eligible for and receive EQIP payments. In fact, farmers must apply for EQIP payments and be accepted into the program. In addition, EQIP may face financing constraints that would limit payment availability. This possibility is not considered in this analysis.

where *m* is the set of manure crop activities (corn, soybean and other crops, either spread or injected) and *mi* is the set of all cropping activities on which manure is injected.

The quantity of hogs that produce manure applied off-farm equals the total manure nitrogen produced times divided by the manure nitrogen available to crops per hundredweight of hogs NH_e (which depends on the cover technology):

$$(11) \qquad hogs\_off_r = manN\_off_r \left(\frac{COV_r}{NH_{\text{cov}}} + \frac{1 - COV_r}{NH_{un\,\text{cov}}} \right)$$

Manure transported off-farm equals total manure produced (hogs produced times manure per hog) minus the manure that is applied on-farm:

$$(12) \quad manN\_off_r = X3_{hogs,r} \left(COV_r \cdot NH_{\text{cov}} + (1 - COV_r) NH_{un\,\text{cov}} \right) - manrate_r \sum_{i \in m} X3_{ir} A_{i,\,fertN,r}$$

The manure used on farm equals the pounds of manure nitrogen applied on farm if it were applied at an agronomic rate (the rate at which chemical fertilizers are applied) multiplied the factor, $manrate_r$. From the survey we know the average rate at which manure is applied to receiving land, but we do not know the rate applied to individual crops. Consequently, we assume that farmers apply manure at the same factor above the agronomic rate for all crops. There are equations analogous to (11) and (12) for pit storage operations.

Policy 1: Nitrogen application constraint. CAFO rules require a nutrient management plan that requires growers to apply manure nitrogen at or below the rate at which plants can absorb (the agronomic rate). This policy is imposed by constraining $manrate_r$ to be less than or equal to 1.

Policy 2: EQIP payments. The effect of EQIP payments can be modeled by adjusting the share of off-farm manure transportation costs borne by EQIP and by adjusting the per-unit subsidy for crops produced in accordance with CAFO application guidelines.

Policy 3: Ammonia nitrogen emission constraint. Hypothetical ammonia emissions regulations are modeled by imposing a limit *Amlimit* on the quantity of nitrogen from ammonia per-unit of hog produced. Nitrogen emissions per unit of hog produced AmN_e depend on manure storage and handling technologies. The ammonia emission constraint is:

$$(13) \qquad COV_r * AmN_{Cover} + (1 - COV_r) * AmN_{Uncover} \leq Amlimit$$

for lagoon operations and:

$$(14) \qquad INJ_r * AmN_{Inject} + (1 - INJ_r) * AmN_{Surface} \leq Amlimit$$

for pit storage operations. Note that the ammonia emission constraint does not depend on the quantity of manure transported off-farm. The application method (spread/inject) is assumed to be the same on-farm and off-farm.

3. Results

In the next subsection we focus on single-medium environmental policies. First we analyze the recently adopted EPA requirements for CAFOs under the Clean Water Act and separately consider the EQIP payments accompanying the CAFO regulations. Second, we consider a potential air quality (Pm2.5) restriction for CAFOs under the Clean Air Act – assuming the nutrient application standards had not been implemented. We then illustrate environmental tradeoffs associated with these two single-medium policies. In subsection 3.2 we consider implementation of multimedia environmental policies.

3.1 Single-medium environmental policies

Table 1 presents the levels of production, inputs, nitrogen to soil and air, and emission technologies under four policy scenarios. The outcome of each policy is compared to 1998 - the year of the survey to which the model is calibrated. Column 1 of table 1 shows that before implementation of the CAFO rules, all hog manure is applied on-farm to corn, soybean, and other crops at a rate equivalent to 7.4 times the agronomic rate on average. This very high rate reflects the quantity of manure produced by farms relative to the amount of land on which manure was spread in 1998. Initially about 10 times as much ammonia nitrogen is released from manure storage facilities (lagoons and pits) as compared to fields. Total nitrogen released to the air in the form of ammonia is about twice the total quantity of manure nitrogen applied to crops and almost three times the quantity that is not absorbed by the crops.

Column 2 presents the effect of the CAFO nitrogen soil application standard enacted in 2003. This policy requires farmers to adhere to a nutrient management plan specifying that nutrients are applied to crops at an agronomic rate. The nutrient application plans effectively eliminate excess nitrogen applied to the soil. The nutrient application standard does induces a slight increase in the quantity of ammonia nitrogen emitted from fields, mainly because farmers respond to the standard by switching from injection to surface manure application techniques in order to minimize their off-farm manure transportation costs. However, the net effect of the policy on ammonia nitrogen emissions is a very small decline, which can be attributed mainly to the small decline in hog production.

To conform with nutrient management plans, CAFOs increase the share of their own land on which they apply manure, decrease the share of the land cultivated using chemical fertilizer, and increase exports of manure off-farm. Profits from the hog operation and total profits decline about 4.3% and 3.6%, respectively. The results are of the same order of magnitude to those obtained by Ribaudo et al (2003), even though the methodology used by that study differs substantially from that used here. At the farm level, Ribaudo et al estimate the net costs of following a nutrient standard by region and farm size using a modified Fleming model (Fleming et al, 1998). Their approach does not account for EQIP payments nor does it allow for optimal farm-level response in terms of crop allocation, input levels, output levels, or production choices such as injection versus spreading of manure. Ribaudo et al estimate that operations in the Mid-Atlantic and South and West regions incur cost increases of about 5% while operations in Corn Belt actually experienced declines in net costs of about 2%.

The effect of EQIP payments is shown in column 3. EQIP is assumed to pay 50% of the costs of transporting manure off-farm. CAFOs respond to the lower effective manure transportation cost by transporting more manure off-farm, and by reducing the substitution between cropland under chemical and manure fertilization regimes. EQIP also offers payments to farmers for land cultivated according to a manure management plan. As a result, hog operation and farm profits decline from the base level by only 2.2% and 1.4%, respectively. This is about half the decline experienced without EQIP payments, and is equivalent to an $81 million net benefit to farmers.

Column 4 presents the effects of an ammonia nitrogen limit applied on a per-hog output basis. For this analysis, ammonia nitrogen emissions are constrained to 15% above the minimum obtainable limit – the level obtained by employing widely available ammonia reducing technologies (lagoon covers and manure injection). For this analysis we assume there is no CAFO manure application standard or EQIP payments. The ammonia nitrogen standard induces pit operations to switch manure application technique from surface-spread to injection on some land, and it induces some lagoon operations to cover their lagoons. The standard result in a 40% decline in ammonia emissions from the manure storage facilities (the largest source of emissions) and a 71% increase in emission from the field, for a net decline in air ammonia of 30%. The increase in emissions from fields results because more lagoons are covered. Covering a lagoon increases the nutrient content of the manure that is applied to the field, increasing nitrogen volatilization. Of particular note, the ammonia standard resulted in a dramatic 78% increase in excess nitrogen applied to soil – revealing an important tradeoff between water and air quality.

To explore the tradeoffs between water and air emissions in more detail we perform two simulations. First we examine how the levels of excess soil nitrogen and ammonia nitrogen vary for different nitrogen application standards. Figure 1 illustrates the result of this simulation. The application standard is relaxed incrementally from full implementation (where manure must be applied at the agronomic rate for all crops). As shown in figure 1, relaxing the standard by 50% results in a large increase in the excess nitrogen applied to the soil, but almost no change in the amount of ammonia nitrogen released. The reason for the limited response is that increasing the soil nitrogen standard provides some incentive for farms with pit storage to surface apply rather than inject the manure, but this effect is small. Lagoon operations have no incentive to cover their lagoons, so there is no significant change in ammonia emission for these operations.

The second simulation, shown in figure 2, examines how soil and air nitrogen levels respond to varying ammonia nitrogen standards. Moving along the x-axis, the ammonia standard declines from the minimum ammonia nitrogen limit attainable under widely available technologies (lagoon covers, and manure injection). Relaxing the ammonia limit by 50% results in a sizeable increase in ammonia emissions and a comparable decline in excess soil emissions. Tightening the ammonia standard causes a large increase in excess soil nitrogen for two reasons. First, a tighter ammonia standard induces more lagoon operations to cover their lagoons. Because more lagoons are covered, the nutrient content of the manure is greater, resulting in more manure nitrogen available for crops. Second, a tighter ammonia standard induces pit operations to expand their use of manure injection as opposed to manure spreading. This increase in manure injection also increases the nitrogen available to crops.

3.3. Multimedia environmental policies

Multimedia environmental policies may increase social welfare relative to single-medium policies. Figure 3 illustrates an isocost curve for a representative CAFO and two hypothetical social indifference curves. Holding costs equal to the cost of imposing only the nutrient application standard $\overline{S}$, social welfare is maximized at the soil and ammonia standards indicated by (S^*, A^*). Reflecting the results of the simulations discussed above, figure 3 shows that imposition of a single-medium ammonia standard $\overline{A}$ results in an *increase* in excess soil nitrogen.

For the same cost to producers as the CAFO nutrient application policy it may be possible to design a coordinated soil and air regulatory regime that raises social welfare. However, future policy decisions are likely to focus on the design of regulations to reduce ammonia nitrogen emissions while maintaining CAFO nutrient application standards. This analysis can provide useful information for this regulatory approach. Figure 4 illustrates the rate of ammonia abatement technology adoption as a function of the ammonia nitrogen standard. Lagoon operations begin to cover lagoons when the ammonia limit is below 90% of the minimum ammonia limit. Below 90%, the rate of lagoon coverage increases proportionally with the ammonia limit. In contrast, about 47% of pit operations inject manure into the soil in the absence of any ammonia policy. Injection rates do not increase until the ammonia limit is about

30% above the minimum limit, after which the injection rate increases at an increasing rate. By definition, all lagoon farms cover their lagoons, and all pit operations inject manure when the ammonia limit is at the minimum level.

Figure 5 illustrates the ammonia nitrogen reduction and the cost of this reduction at varying levels of the ammonia limit. We estimate that ammonia nitrogen can be reduced at a minimum cost of $1.22 per pound when the ammonia limit is set at 40% above the minimum. The cost reducing ammonia nitrogen remains less than $1.50 per pound if the ammonia limit is set between 0-80% of the minimum.

Finally, we consider the environmental and economic effects of adding the ammonia nitrogen emission standard evaluated in column 4 of table 1 to the 2003 CAFO-EQIP regime evaluated in column 3. Results of this analysis are presented in column 5 of table 1. Relative to the single-medium soil application standard with the EQIP payments, the multimedia policy is quite costly. Hog operation and total farm profits decline by 10.4% and 8.6% relative to the base year, compared to 2.2% and 1.4% without the ammonia standard. However this policy reduces ammonia nitrogen by about 30% relative to the levels under CAFO-EQIP alone.

4. Conclusions

The US Environmental Protection Agency recently began enforcing regulations requiring that CAFOs apply manure in accordance with a nutrient management plan. These regulations are designed to reduce excess nitrogen applied to the soil, and do not control emissions of nitrogen in the form of ammonia from manure storage facilities and from fields on which manure has been applied. Ammonia nitrogen emissions can cause acid rain, odor nuisances, and can react with trace gases in the atmosphere to affect particulate matter and haze. Ammonia nitrogen emissions could conceivably be regulated under the PM2.5 particulate standard of Clean Air Act. This paper considered the economic and environmental implications of regulating both water and air nitrogen emissions under single-environmental medium and coordinated multi-environmental media policies.

Model results indicate the CAFO nutrient application standards lower hog farm profits (returns to labor) by 3.6%. However, assuming all CAFO operations apply for and receive EQIP payments, then these payments reduced CAFO profit losses to only 1.5%. A hypothetical ammonia nitrogen standard was estimated to reduce welfare by 7.1%, and a hypothetical multimedia-policy incorporating both soil and air standards lowered welfare by 8.6%. The soil standard eliminated excess soil nitrogen and the ammonia standard reduced air emissions by about 30%.

This study highlighted the environmental and economic tradeoffs that can occur with single-medium environmental policies. We found that enforcement of a single-medium ammonia nitrogen standard induces farmers to apply more excess nitrogen to the soil - a result likely to diminish water quality through increased nitrogen run-off and leaching. The ammonia standard causes an increase in excess soil nitrogen for two reasons. First, the ammonia standard induces some operations to cover their lagoons, which raises the nutrient content of manure. When manure with higher nutrient content is applied to fields, more nitrogen is available for crops. Second, an ammonia standard induces some operations to expand their use of manure injection as opposed to manure spreading. This increase in manure injection also increases the nitrogen available to crops. Because of high manure transportation costs, farmers do not fully compensate for the additional nutrients available to crops from manure by increasing the amount of land on which they spread manure.

The study found that imposing a single-medium nutrient application standard consistent with the 2003 EPA regulations has only a negligible effect on ammonia nitrogen emissions. Lagoon operations, which are initially uncovered, cannot respond in a way that exacerbates air ammonia emissions. Pit operations do face an increased incentive to surface apply rather than inject the manure, but the effect on air emission is small.

The analysis considered only hog farms. Future work could incorporate dairy, livestock, and poultry operations. A further analysis could also include possible EQIP payments to be associated with air emission standards. The model developed here could also be used to estimate the payments required to induce operators to cover their lagoons and inject manure.

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Appendix: Variable Definitions and Sources of Data

Table A1. Initial production, $X0_{ir}$

Outputs	Units	Value	Source
Corn fertilizer	100 bushels	*	USDA ARMS Survey 1998
Corn manure surface	100 bushels	*	USDA ARMS Survey 1998
Corn manure inject	100 bushels	*	USDA ARMS Survey 1998
Soy fertilizer	100 bushels	*	USDA ARMS Survey 1998
Soy manure surface	100 bushels	*	USDA ARMS Survey 1998
Soy manure inject	100 bushels	*	USDA ARMS Survey 1998
Other fertilizer	$ (VOP)	*	USDA ARMS Survey 1998
Other manure surface	$ (VOP)	*	USDA ARMS Survey 1998
Other manure inject	$ (VOP)	*	USDA ARMS Survey 1998
Hogs	CWT.	*	USDA ARMS Survey 1998

* Estimated mean value varies by region and size of operation

Table A2. Output price, P_{ir}

Outputs	Units	Value	Source
Corn (all)	$/100 bushels	284	NASS – (average price 1997-99)
Soy (all)	$/100 bushels	700	NASS – (average price 1997-99)
Other (all)	-	1	-
Hogs	$/cwt.	46.92	NASS –(average price 1997-99)

Table A3. Input price, W_{jr}

Inputs	Units	Value	Source
Land	$/acre	68.2	NASS Agricultural Land Values Final Estimates 1998, Statistical Bulletin Number 957 (national average) (use 7% of land value as rental rate)
Capital	$	1	(by definition)
Feeder Pigs	$/cwt	80.25	NASS – (average price 1997-99)
Feed Corn	$/100 bushels	284	same as corn
Feed Soy	$/100 bushels	700	same as soy
Fertilizer - N	$/lb.	0.185	NRCS (and ERS, AER 824, p.35)

Table A4. Resource Use, A_{ijr}

Input-output	Units	Value	Source
Land-corn	acres/100 bushels	*	USDA ARMS Survey 1998
Land-soy	acres/100 bushels	*	USDA ARMS Survey 1998
Land-other	acres/$	*	USDA ARMS Survey 1998
Capital-corn	$/100 bushels	49.3	ERS Statistical Bulletin 974
Capital-soy	$/100 bushels	127	ERS Statistical Bulletin 974-4
Capital-other	Share of value	0.17	Same rate as corn
Capital-hogs	$/CWT.	*	USDA ARMS Survey 1998
Feed corn-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feed soy-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feeder pigs-hogs	CWT/CWT	*	USDA ARMS Survey 1998
Fertilizer-N-corn	lbs./ 100 bushels	80.0	Manure application standard, Kellogg, R.L., C.H. Lander, D. Moffitt, and N. Gollehon. 2000.
Fertilizer-N-soy	lbs./ 100 bushels	236.7	“”
Fertilizer-N-other	lbs./ $	0.282	Same rate as corn

* Estimated mean value varies by region and size of operation

Table A5. Manure off-farm transportation net costs ($/CWT hog) by region and manure storage and handling technology, T_{re}

Manure Storage	Storage or Handling Technology	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
Lagoon	Uncover	1.33	1.36	2.01	2.15
	Cover	5.32	5.38	6.57	6.83
Pit	Surface	1.20	1.25	2.29	2.53
	Inject	1.61	1.66	2.82	3.08

Source: Estimated. Base manure handling costs from Fleming et al. 1998. Unit mile cost from USDA, NRCS, 2003 *Costs Associated with Development and Implementation of Comprehensive Nutrient management Plans*. Lagoon cover costs from Massey, et al. *Agronomic and economic impacts of lagoon based swine operations complying with the proposed EPA zero discharge rule*.

Table A6. Nitrogen available to crops and nitrogen ammonia emissions by manure storage and handling technology

Manure Storage	Storage or Handling Technology	Soil Nitrogen available to plants, $Npercwt_e$ (lbs/CWT)	Air ammonia emissions from house and storage (lbs/CWT)	Air ammonia emissions from land application (lbs/CWT)	Total air ammonia emissions, AmN_e (lbs/CWT)
Lagoon	Uncover	1.53	7.21	0.42	7.62
	Cover	5.07	2.69	1.39	4.08
Pit	Surface	4.83	3.00	1.32	4.32
	Inject	5.95	3.00	0.20	3.20

Source: US EPA *National Emission Inventory-Ammonia Emission from Animal Husbandry Operations*, 2004.

Table A7. EQIP payments per unit of output by crop and region

Crop	Unit	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
Corn	$/100 bu	8.87	8.28	53.00	49.70
Soybean	$/100 bu	27.44	24.44	85.62	86.92
Other	Share of value	0.05	0.11	0.13	0.17

Source: Estimated using EQIP program data, Farm Service Agency, USDA.

Table 1. Production, Inputs, Nitrogen to Soil and Air, and Emission Technology under Four Policy Scenarios

	1. Base	2. CAFO		3. CAFO+EQIP		4. Amm. N limit		5. CAFO+EQIP+Amm.N	
			% chg.		% chg.		% chg.		% chg.
Hogs (mil. cwt.)	119.16	118.74	-0.35	118.88	-0.23	118.78	-0.31	118.01	-0.96
Corn – chem. fertilizer (mil. bu.)	106.14	106.29	0.15	106.04	-0.09	107.54	1.32	108.10	1.85
Corn – manure spread (mil. bu.)	58.97	66.41	12.60	63.93	8.40	50.59	-14.22	52.53	-10.94
Corn – manure inject (mil. bu.)	32.26	32.20	-0.19	32.60	1.07	40.79	26.45	41.42	28.39
Soybean – chem. fertilizer (mil. bu.)	47.91	47.69	-0.46	47.69	-0.44	47.86	-0.09	48.06	0.33
Soybean – manure spread (mil. bu.)	5.19	5.99	15.47	5.73	10.52	3.97	-23.43	4.17	-19.56
Soybean – manure inject (mil. bu.)	0.54	0.52	-2.81	0.53	-0.56	0.55	2.15	0.55	2.41
Other – chem. fertilizer (mil. $.)	98.02	87.35	-10.88	89.23	-8.97	94.42	-3.68	87.91	-10.31
Other – manure spread (mil. $.)	11.39	14.42	26.59	14.12	23.94	11.45	0.53	13.10	14.95
Other – manure inject (mil. $.)	7.25	6.36	-12.31	7.38	1.74	12.58	73.47	13.07	80.22
Land (mil. acres)	3.58	3.58	0.00	3.58	0.00	3.58	-0.06	3.58	-0.05
Capital (mil. $)	1116	1116	0.00	1116	0.00	1113	-0.30	1108	-0.71
Feeder pigs (million cwt.)	16.60	16.54	-0.37	16.56	-0.24	16.54	-0.38	16.41	-1.16
Feed corn (mil. bu.)	671.55	669.29	-0.34	670.05	-0.22	669.42	-0.32	664.92	-0.99
Feed soybean (mil. bu.)	89.05	88.75	-0.34	88.85	-0.22	88.77	-0.32	88.17	-0.99
Chemical nitrogen (1000 tons)	113	111	-1.51	111	-1.35	113	0.00	113	-0.40
Revenue (mil. $)	6645	6643	-0.04	6657	0.18	6625	-0.30	6610	-0.53
Input costs (mil. $)	2788	2789	0.02	2788	0.00	2784	-0.16	2759	-1.06
Total profits (mil. $)	3857	3720	-3.56	3801	-1.45	3583	-7.11	3524	-8.63
Hog operation profits (mil. $)	3191	3054	-4.30	3121	-2.20	2931	-8.15	2859	-10.41
Ammonia N - storage (1000 tons)	327.6	326.5	-0.34	326.9	-0.22	195.1	-40.43	193.8	-40.84
Ammonia N - field (1000 tons)	33.8	34.4	1.77	34.1	0.74	57.9	71.19	57.5	70.13
Ammonia N – total (1000 tons)	361.4	360.9	-0.14	360.9	-0.13	253.0	-29.99	251.3	-30.46
Excess N - soil (1000 tons)	137.9	0.0	-100.00	0.0	-100.00	245.1	77.82	0.0	-100.00
Rate (factor of agronomic rate)	7.4	1.0	-86.42	1.0	-86.42	17.1	131.80	1.0	-86.42
Manure transport. costs (mil. $)	0.0	134.0	-	136.0	-	0.0	0.00	142.7	-
Manure N on-farm (1000 tons)	183.8	50.1	-72.75	49.1	-73.30	290.4	58.05	46.9	-74.50
Manure N off-farm (1000 tons)	0.0	132.3	-	133.9	-	0.0	0.00	241.7	-
Cover (%)	0.00	0.00	0.00	0.00	0.00	39.12	-	39.12	-
Inject (%)	25.56	24.19	-5.34	24.92	-2.48	32.91	28.76	32.68	27.87

Figure 1. Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying soil nitrogen standards

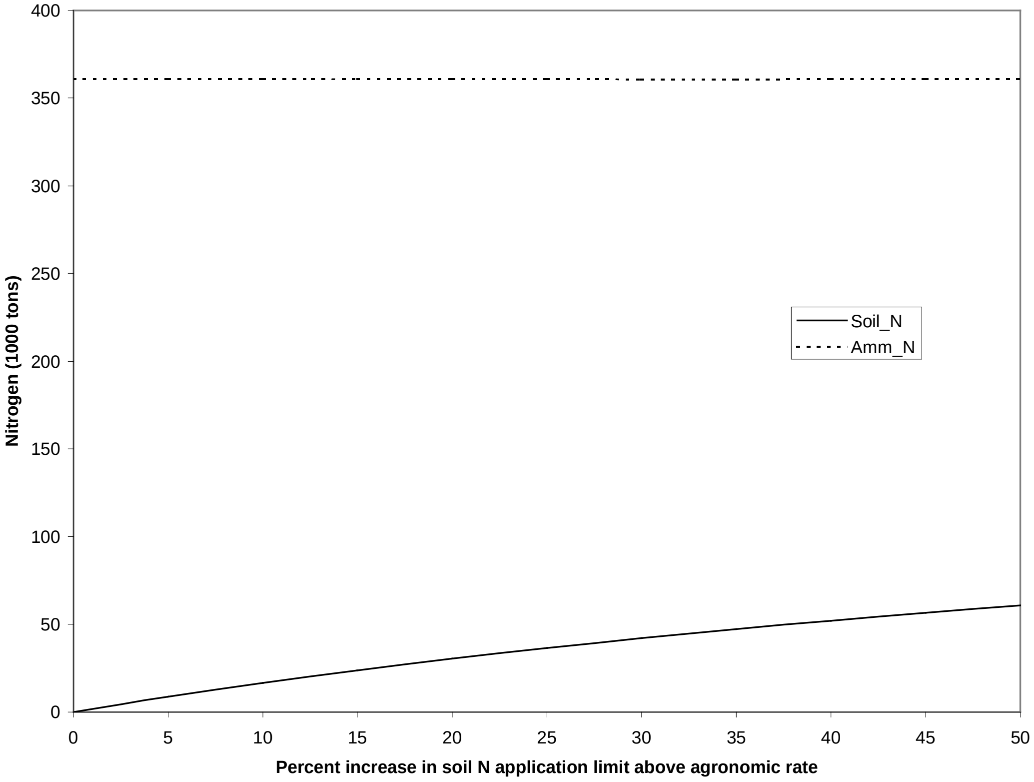

Figure 2. Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying ammonia nitrogen standards

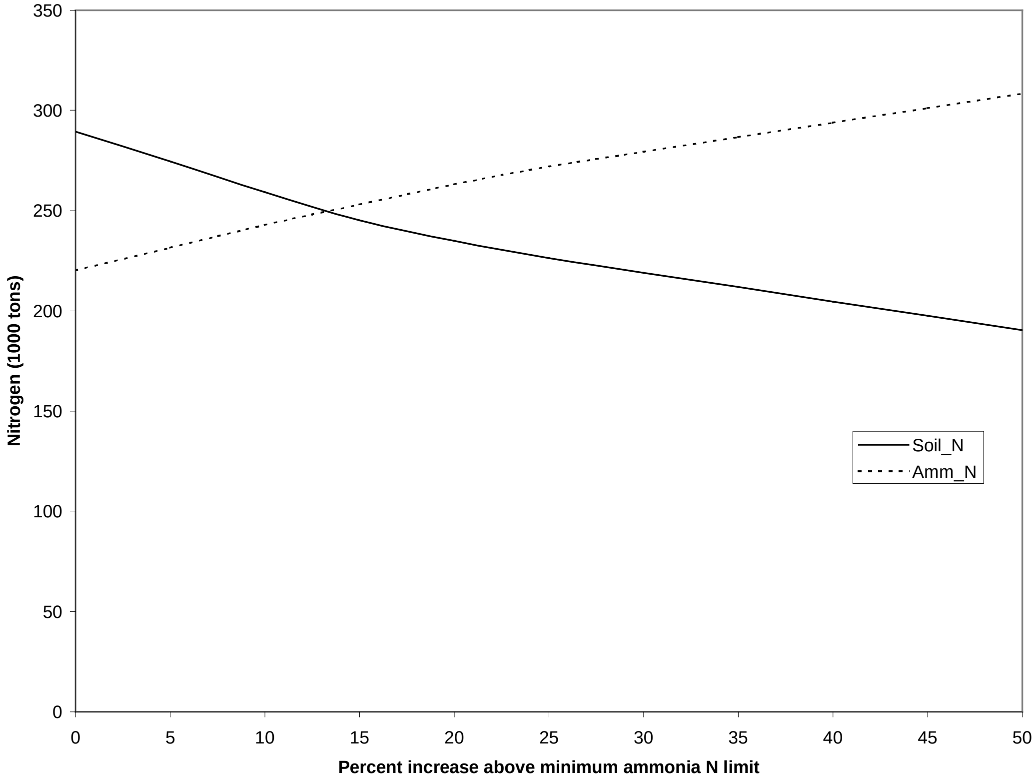

Figure 3. Isocost for representative CAFO and hypothetical social indifference curves

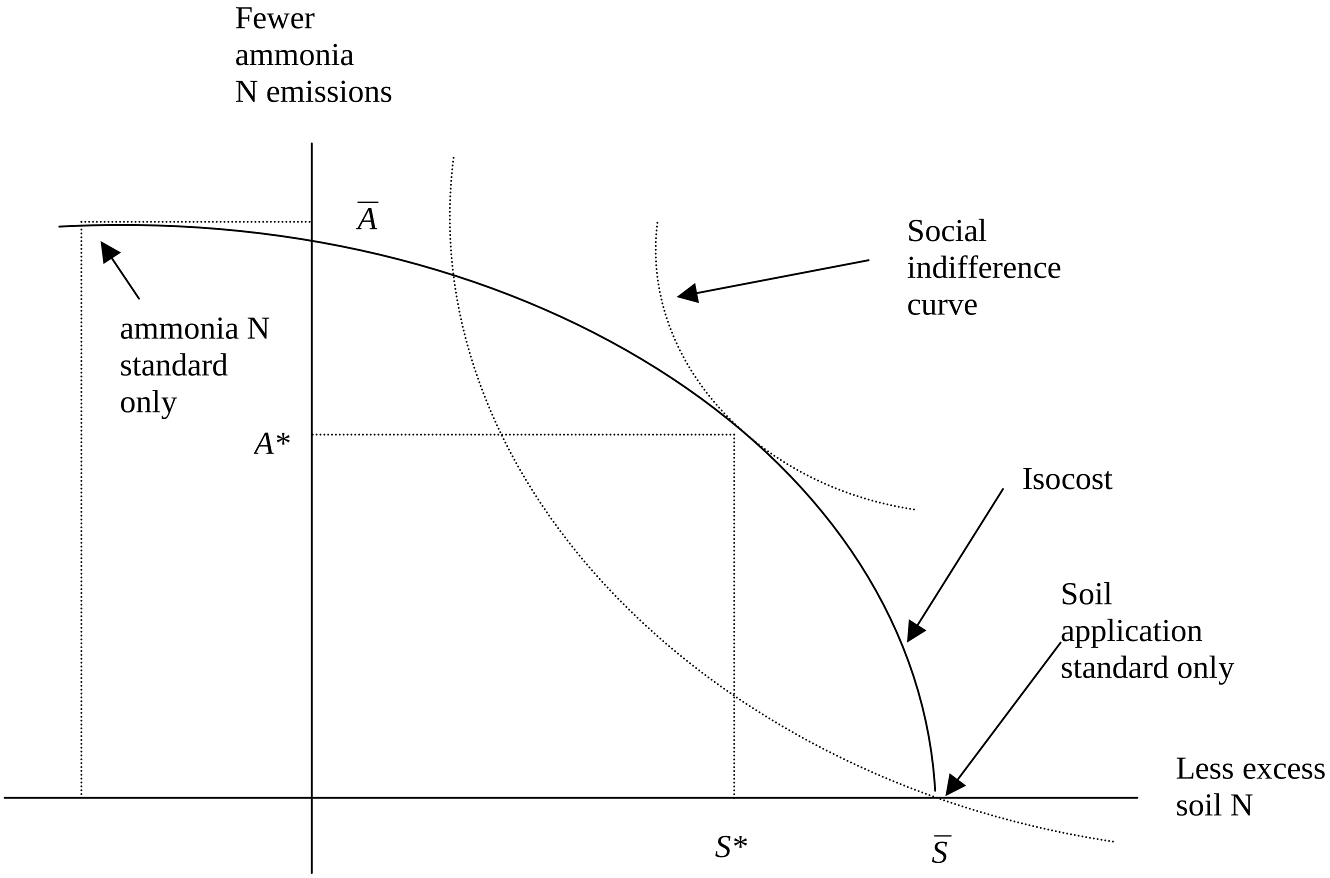

Figure 4. Rate of technology adoption as a function of ammonia nitrogen standard

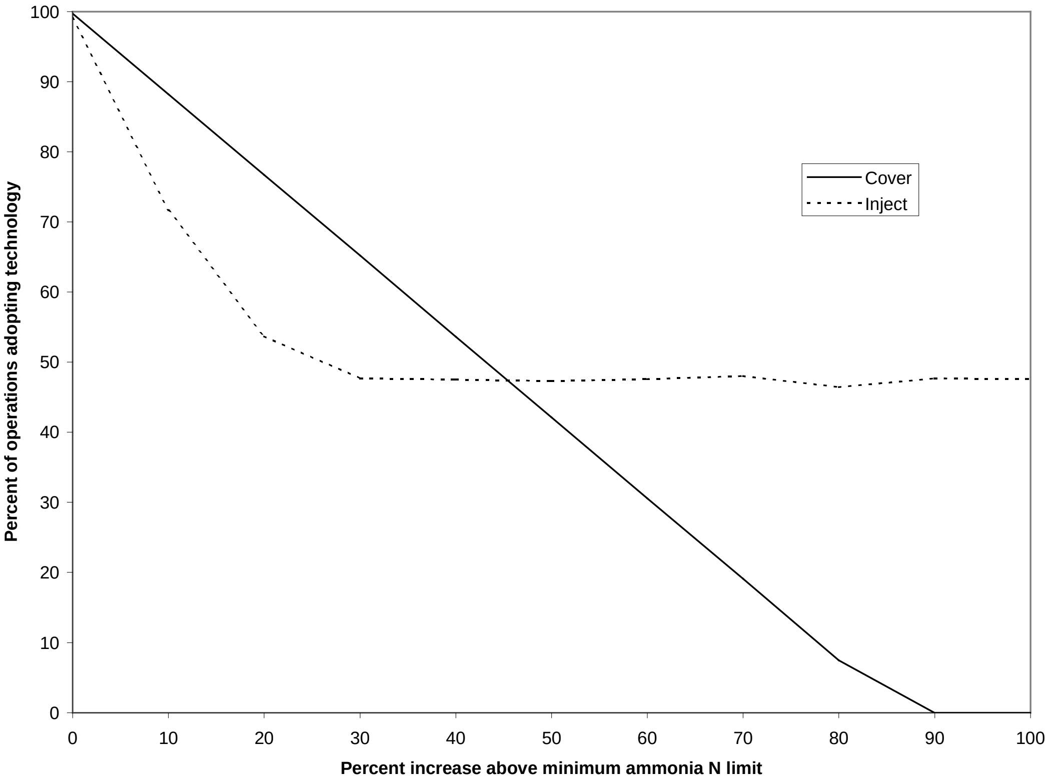

Figure 5. Ammonia nitrogen reduction and compliance cost as a function of ammonia nitrogen standard