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AN ECONOMIC ANALYSIS OF ENVIRONMENTAL REGULATIONS ON SWINE WASTE MANAGEMENT

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I. Introduction

Generation of wastes such as manure and odor is inevitable in the animal production process. Traditionally, animal manure which contains major plant nutrients has always played an important role as a source of crop nutrients. In reality, some livestock producers who apply manurial fertilizers to cropland consider the manure as a useful by-product, while other producers consider the manure as a waste product that impedes the operation. As the livestock production systems have moved toward highly concentrated and large operations, animal manure has gradually turned from a fertilizer resource into a waste material due to resource constraints. The trend of shifting into large intensified production facilities has been particularly noticeable in the U.S. swine-pork industry. Large scale of swine production systems have substantial advantages in purchasing inputs and marketing outputs over smaller operations, portending that the shift to larger operations will probably continue. While the rapid expansion of the U.S. swine industry has increased producers' income and employment opportunities, the potential burden in the major production area has placed on local environment by increasing the waste generation.

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A significant amount of public awareness has been directed toward waste water and nuisance odors released from hog barns and manure handling systems. Federal and state laws have been enacted to protect the nation's water, air, and other natural resources. Two federal statutes, the *Clean Water Act* of 1972 which was primarily designed to protect the waters from point source pollutants and the *Coastal Zone Act Reauthorization Amendments* of 1990 which was designed to reduce non-point pollution, impose regulatory requirements on *Concentrated Animal Feeding Operations* (CAFO).[1] Under these circumstances, swine producers have been forced to reconsider the efficiency of manure management in their operations to increase profitability and for environmental responsibility. In addition, the environmental regulators and planners have an interest in regulatory tools that minimize environmental degradation from swine operations. In this context, the information on the economic impacts of environmental regulations on swine production operations is needed. Little information is available from previous studies to evaluate the overall economic effects (profitability, land use, equipment, and manure value) of environmental regulations on swine producers' resources.

The objective of this paper is to analyze the economic impact of environmental regulations on swine waste management in the Oklahoma Panhandle area. The rest of this paper is organized as follows. Section II outlines the environmental economic issues on swine waste management. The linear programming model for analyzing swine waste problems under theenvironmental regulations is formulated and applied in Section III. Section IV discusses the analytical results and Section V makes some concluding remarks.

II. Environmental Economic Issues on Swine Waste Management

Swine waste management system, as an integral part of a well-

[1] Concentrated Animal Feeding Operations (CAFOs) is a lot or where animals are fed or maintained for a total of 45 days or more in a twelve-month period. In the case of swine operations there must be more than 2,500 swine each weighing over 55 pounds in the same operation. This type of operation must obtain a permit.

planned swine feeding operation, requires simultaneous consideration of the swine production system, the manure handling system, and the crop production system. As shown in (Figure 1), swine waste is a by-product which consists of water, feces and urine, and bedding material.[2] Swine manure which consists of approximately 60 percent feces and 40 percent of urine can be evaluated in terms of its nutrients (e.g., nitrogen, phosphorus, potassium), 5-day biochemical oxygen demand (BOD_5), and 5-day chemical oxygen demand (COD_5). The properties of swine manure are significantly affected by many factors such as the physiology (size, sex, breed, and activity) of the animal, the feed ration (digestibility and the protein and fiber content), and the climatic environment (temperature and humidity). In general, the quantity of feces and urine generated from a swine operation increases with the weight and feed intake of the animal.[3] Daily animal manure production averages 6.5 percent of body weight and ranges from 2.3 to 13 pounds per animal. Traditionally, swine manure played an important role in agricultural production as a source of crop nutrients since the manure delivers major nutrients (e.g. nitrogen, phosphorus, and potassium) in fixed proportions. As shown in (Table 1), the portions of the nutrient content in the finishing pig (weight of 200 pounds) manure contains approximately 0.09 percent of nitrogen and 0.07 percent of phosphorus on the basis of per pound of body weight. In applying the manure to the cropland, the amount of nitrogen nutrient contained in raw manure is lost by the types and length of storage and the application methods. The losses are attributed to volatilization, leaching, percolation, runoff, and wind or water erosion. The ratio of nitrogen versus phosphate (N/P) in the raw manure is estimated to be approximately 1.32 while the ratio is estimated at 1.06 in the anaerobic storage pit due to about 40 percent loss of nitrogen. This represents that swine manure contains a relatively high phosphorus nutrient. Major crops such as corn and wheat need relatively more nitrogen than phosphorus. For example,

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[2] The terms of swine manure and waste are sometimes used synonymously in the literature. In this paper, swine manure refers to combination of feces and urine only, and swine waste includes manure plus other materials, such as bedding, wasted feed, and water that is wasted or used for sanitary and flushing purposes of swine.

[3] For more detailed description of the swine manure characteristics, see Midwest Plan Service (1985, p.2.1) and Loehr (1984, pp.76~77).

FIGURE 1 Schematic Representation of Swine Waste Management System

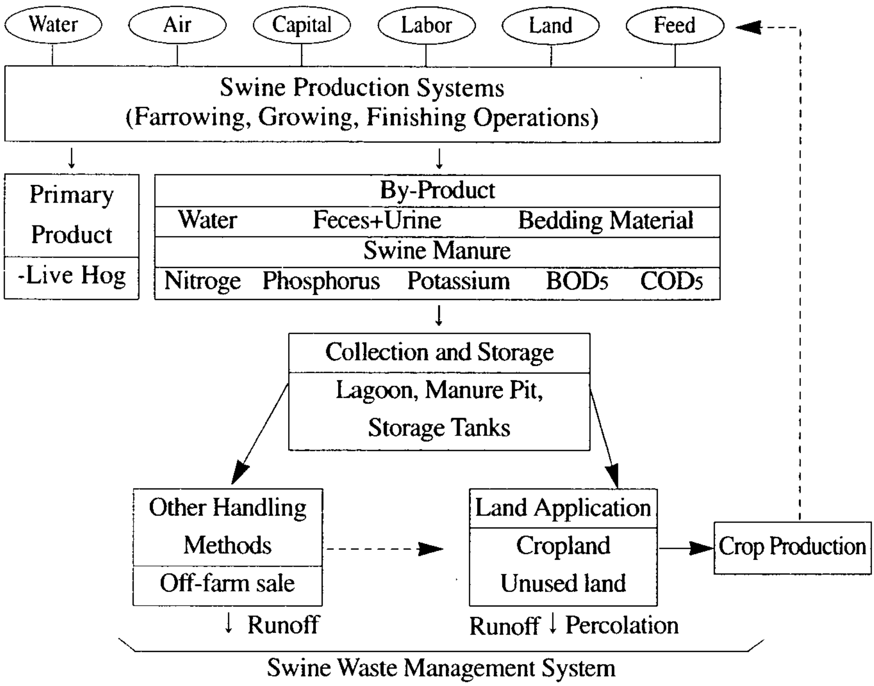


TABLE 1 Nutrient Contents of Manure as Affected by Type of Storage and Nutrient Requirements for Corn

Nutrients	Raw Manure[1] (per pound, a body weight)	Anaerobic[2] Storage	Lagoon Liquid+ Sludge	Lagoon Liquid Only[3]	Corn[4] (lb/acre)
Nitrogen	0.090	0.063	0.019	0.013	240
Phosphorus	0.068	0.057	0.017	0.006	100
Nitrogen/ Phosphate Ratio	1.32	1.06	0.33	2.17	2.40

Note: [1] Raw manure includes feces and urine with no bedding.
[2] Surface application followed by cultivation.
[3] Applied by sprinkler irrigation.
[4] The required uptake level of nutrients is assumed to be 180 bushel/acre of expected yield.

Source: Midwest Plan Service (1993).

the ratio of N/P in the corn production is estimated to be 2.40 due to higher uptake level of nitrogen.[4] So, applying swine manure to satisfy crop nitrogen needs usually implies that phosphorus and potassium are supplied in excess of crop needs.

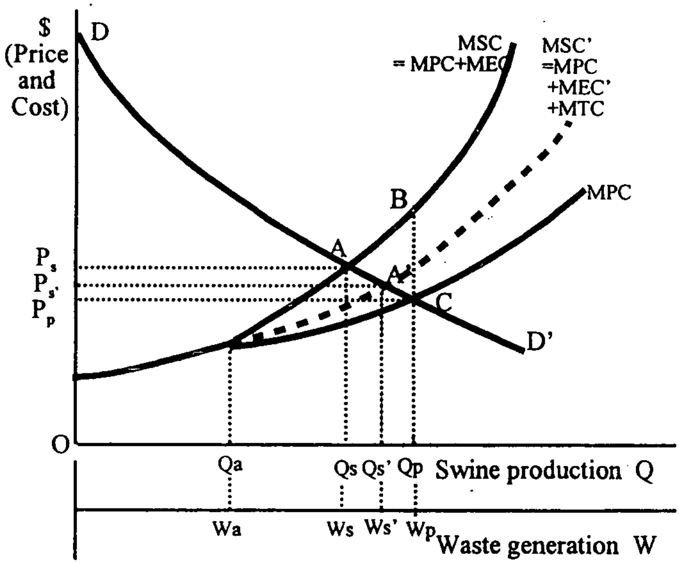
In reality, some runoff and leaching of manure nutrient is a natural consequence of swine feeding operations, but potential pollution problems caused by swine waste are generally intensified by two factors such as improper waste handling and animal density. Economic efficiency has caused swine production to become more concentrated relative to the area available for disposal. As production operations become more intensified, the value of swine manure changes from a fertilizer resource into a waste material when treatment and application costs exceed the benefit of manure utilization. In addition, runoff and odor emissions from feedlots, storage facilities, and land where manure is applied are potential sources of pollution. Odors generated from livestock systems, while generally considered non-toxic, may affect human well-being by eliciting unpleasant sensations and causing other physical reactions. There is little agreement on what is an acceptable odor intensity or how long one should tolerate anobjectionable odor.[5] In this paper, we will focus on issues related to water quality.

Economists view the environmental issues associated with swine waste disposal as negative externalities. Negative externalities include: (1) improper manure disposal where excess nitrogen and/or phosphorus leaches into the groundwater or contaminates the surface water, and (2) the released ammonia and other compounds into the air leading to air pollution. In analyzing the negative externality problems, the environmental damages begin at the point where the capacity of the environment to assimilate waste is exceeded. As production units increase in size, the assimilative capacity of the

[4] The basic parameters of manure nutrients and plant uptake level is drawn from the Livestock Waste Facilities Handbook (Midwest Plan Service, 1993).

[5] Odor is context-dependent so that perceptions of the quantity of a particular odor vary across individuals and groups. Odors may not be universally classified because perception is associated with emotions and memory. So far, no satisfactory apparatus has been developed for odor measurement despite technical advances in the development of gas measuring equipment. For more detailed odor perception, see Lohr (1996).

FIGURE 2 Swine Waste Treatment for Correcting Negative Externalities



environment in areas immediately surrounding a swine production facility can be quickly outstripped. Optimal private waste treatment decisions may ignore external damages incurred by downwind users of air and/or downstream users of water resources. From the environmental policy perspective, the mechanism of decision making associated with swine waste management could be explained by the diagrammatic approach, as presented in (Figure 2). The demand for the swine product is represented by DD' while the private marginal cost of swine production is represented by MPC. Environmental damages occur when the waste generated W^a by the production Q_a exceeds the assimilative capacity of the surrounding environment. Marginal Social Cost (MSC) is the sum of marginal private cost (MPC) and marginal external cost (MEC). If the externality is unmitigated, swine production is Q_p with market price P_p. The optimal social level of production is Q_s with price Ps. The deadweight loss is equal to area ABC. Waste treatment is desirable in the social sense if the marginal cost of treating the waste (MTC) plus the cost of marginal damages from any wastes remaining after treatment (MEC') are less than the MEC in the untreated case. i.e.. MEC'+MTC < MEC.

However, the marginal social cost after treatment declines to MSC' if the value of any remaining environmental damages after treatment plus the marginal treatment cost are less than the MEC without waste treatment. With the desirable waste treatment (in Figure 2), the optimal social price with the treatment declines to P_s' and the optimal social level of swine production increases to Q_s'. If the MEC' curve should lie above the MEC curve, then the untreated position W_s and P_s should be adopted. In this paper, the size of the production operation and waste treatment facility subject to land resource and environmental regulations will be endogenously determined and evaluated.

III. Modeling Formulation for Analyzing Swine Waste Problems

As presented above, a swine producer is concerned with allocating resources to maximize net returns while selecting the waste handling system which most efficiently meets environmental constraints. Economists have traditionally employed optimization techniques to model farms and make farm management and policy recommendations. It is possible to compare several waste handling systems within a single mixed integer programming model. However, when there is a small number of distinct systems, it is more convenient to analyze each system separately using a linear programming (LP) model.[6] The solutions from several LP models can be compared to determine the best waste management practice. The proposed LP model outlined below is steady- static but is capable of analyzing investments which are assumed to be made instantaneously at the beginning of the planning period. For example, the capacity of the production facility can be predetermined or determined endogenously within the model. The size of production unit is given as the number of sows that can be accommodated. Size of operations

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[6] The framework of analytical techniques for a livestock waste management was described by Foster (1992). In analyzing the issues on livestock waste management, the mixed integer programming models were used by Brundin and Rodhe (1994), and the linear programming model was used by Safley, Haith, and Price (1979) and Bosch and Pease (1993).

may be discrete but can be approximated as a continuous variable. Given the linear function of the total construction cost (TCC), the average construction cost (ACC) and marginal construction cost (MCC) of confinement building and equipment for various sizes of production operations may appear as shown in (Figure 3). This derivation procedures imply the concept of economies of size in estimating construction costs of building and equipment.[7] The capital or construction cost for buildings and equipments for a swine operation unit can be approximated by the following equation:

$$TCC = C_0 + C_1 \cdot NUM_{sw}, \tag{3.1}$$

where TCC = total construction cost of manure handling facility for a swine operation unit
C_0 = fixed cost if any facilities are built
C_1 = marginal cost of adding one more unit of facility
NUM_{sw} = number of swine production units

The annual cost for adding one more production unit is determined by the amortization or capital recovery formula as follows:

$$LC_{sw} = C_1 \cdot \left(\frac{r}{1-(1+r)^{-k}} \right) \tag{3.2}$$

where LC_{sw} = annualized marginal investment cost for a sow unit
C_1 = marginal cost of adding one more unit of facility
r = annual interest rate
k = year of life in handling facility

[7] Technically, the concepts of economies of scale and size are different concepts even though the most convenient measures of these concepts coincide at cost-minimizing point. The economies of scale indicates how output responds as one moves out a scale line from the origin in input space. The economies of size shows the cost response associated with movements along the locus of cost minimizing points in input space. For more detailed exposition of economies of scale and size, see Chambers (1988), pp.68-73.

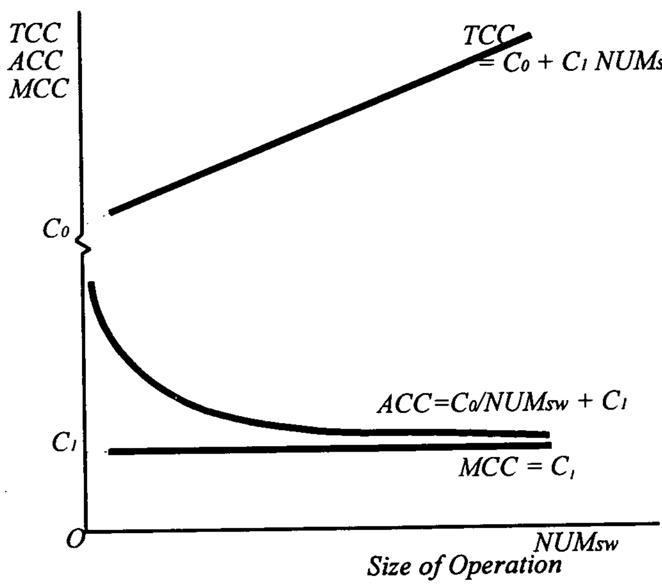
Similarly,

$$AFC_{sw} = C_0 \cdot \left[\frac{r}{1-(1+r)^{-k}} \right], \tag{3.3}$$

where AFC_{sw} = annualized fixed capacity cost
C_0 = fixed cost if any facilities are built

The optimal size of production facility is one where the incremental annual net returns from a unit of added capacity are just equal to the annual incremental cost of adding that unit of capacity. Then, the objective function of the LP model can be stated as the maximization of annual profits after the payment of all marginal investment costs for production units and/or waste treatment facilities as follows:

FIGURE 3 Relationship Among Total, Average, and Marginal Construction Costs for Building and Manure Handling Facility



$$Max\ \Pi = NUM_{sw} \cdot (NR_{sw}-LC_{sw})-\sum_{t} cMNS_t \cdot MNST_t-cMNCP \cdot MNCP+\sum_{i}\sum_{j}[L_{ij} \cdot NRY(F_{nij})-\sum_{n}\sum_{t}(cMNSP_{ijt} \cdot MNSP_{ijt}+cF_n \cdot F_{nij})]-AFC_{sw}, \quad (3.4)$$

where NUM_{sw} = number of swine units (e.g. number of sows)

NR_{sw} = net revenue per sow unit, excluding waste handling costs

LC_{sw} = annualized long term marginal investment cost in production facilities per swine unit

cMNSt = operation and maintenance cost of one unit swine waste in time t

MNSTt = amount of manure in storage at the end of time t

MNCP = total waste holding capacity

cMNCP = annualized marginal investment cost per waste unit which allows for fixed investment cost in waste handling facilities as well

L_{ij} = amount of land or soil type j devoted to crop i

$NRY(F_{nij})$ = net revenue (excluding fertilizer costs) from crops grown on land when F_{nij} units of fertilizer are applied

$MNSP_{ijt}$ = quantity of manure spread on crop i on land j in time period t

$cMNSP_{ijt}$ = cost of spreading one unit of manure on land j for crop i in time t

cF_n = cost of commercial fertilizer n

F_{nij} = quantity of commercial fertilizer for plant nutrient n applied to land j for crop i

AFC_{sw} = annual fixed cost for manure holding facility

i , j, and n = types of crops grown, soil areas, and plant nutrients, respectively

t = index of time period (each time period is equivalent to 90 days due to quarterly classification)

Given this objective function, the constraints on resources which limit the operator's decisions can be formulated. The area of land for each soil type is assumed to be fixed. The required land constraints are given by:

$$\sum_i L_{ij} \leq L_j, \tag{3.5}$$

where L_{ij} = amount of land j by soil type devoted to crop i
L_j = available land j

Environmental regulatory standards may limit the storage and application of waste to land during certain periods of a year. Thus, facilities for manure storage must be constructed to meet the environmental constraints. In order to maintain the balanced inventory of the storage system, two constraints should be considered for each period t. The first constraint is the inventory balance equation which requires that beginning inventory of swine waste plus production of waste within the period is equal to the amount of waste spread on fields plus the ending waste inventory. So, the balance equation for manure storage is given by:

$$MNST_{t-1} + NUM_{sw} \cdot MN_{swt} + \sum_i \sum_j MNSP_{ijt} - MNST_t = 0 \quad \forall t, \tag{3.6}$$

where $MNST_{t-1}$ = amount of manure in storage at the beginning of time t
MN_{swt} = amount of manure generated in time t
$MNSP_{ijt}$ = quantity of manure spread on crop i on land j in time period t
$MNST_t$ = amount of manure in storage at the end of time t

Since this is an annual model, we define the beginning of the production year so that waste capacity is empty both at the beginning and at the end of the year. The second requires that the capacity for waste storage system be large enough to contain accumulated waste plus the net additions of waste during each time period. Environmental regulations often require that additional capacity be available to hold larger than expected rainfall and runoff as follows:

$$MNST_{t-1} + NUM_{sw} \cdot (MN_{swt} + \varphi_{SF}) - \sum_i \sum_j MNSP_{ijt} - MNCP \leq 0 \qquad \forall\ t, \tag{3.7}$$

where $MNST_{t-1}$ = amount of manure in storage at the beginning of time t

MN_{swt} = amount of manure generated for one swine unit in time t

φ_{SF} = safety factor for manure storage

$MNSP_{ijt}$ = quantity of manure spread on crop i on land j in time t

MNCP = total waste holding capacity

As a control variable for environmental regulations, the safety factor could be imposed in terms of added capacity to waste storage to allow for peak rainfall events. For example, SF may include sufficient capacity to hold runoff from the maximum 24 hour rainfall which would occur in a 25 year period. It is convenient to define this on a per swine unit basis. In addition, an environmental regulation may take the form of restricting the amount of animal waste which is applied so that nutrients such as nitrogen and phosphorous do not exceed the uptake of the crop. The regulatory constraint on the nutrient uptake could be imposed by:

$$F_{nij} + MAVF_{nijt} \leq UF_{nij} \qquad \forall\ n, i, j\ , \tag{3.8}$$

where F_{nij} = quantity of commercial fertilizer nutrients n(e.g., nitrogen, phosphorus, and potassium) applied to land j for crop i

$MAVF_{nijt}$ = available fertilizer nutrient n for crop i and soil j from manure spreading in time period t

UF_{nij} = uptake level of plant nutrient n in crop i and soil j

The parameter for determining available fertilizer nutrient from manure spreading is given by:

$$MAVF_{nijt} = [1 - FLOS_{njt}] \cdot MF_n \cdot MNSP_{ijt} \qquad \forall\, n, t, \qquad (3.9)$$

where $FLOS_{njt}$ = loss of nutrient n when it is applied to soil j at time period t

MF_n = amount of nutrient n in manure

$MNSP_{ijt}$ = of manure spread on crop i and land j in time period t

Many states have specific restrictions on the application of nitrogen and some states also limit the amount of phosphorous which can be applied.[8] As mentioned earlier, problems occur because the ratio of nitrogen and phosphorus in the manure applied does not usually correspond to the ratio of nitrogen to phosphorous which is utilized by the crop. Nutrients incorporated into the soil before the crop is planted may be less vulnerable to surface loss but may be more vulnerable to loss through leaching.

IV. Model Application and Analytical Results

A preliminary model has been developed for the Oklahoma Panhandle area (Texas county) where a rapid increase in swine production is occurring. The producer is considering the maximum size of farrow to finish operation (up to a maximum of 1,200 sows) that can be constructed on a 320 acre parcel of which 256 acres are irrigated. The irrigated land can be used to grow wheat or corn. The model is preliminary and estimates of construction costs and coefficients have been obtained from previous studies.[9] (Table 2) shows the derivation of the total, average, and marginal construction costs of building and storage system for alternative sizes of production units. As the size of production units given the linear total

[8] In the regulatory framework for plant nutrient uptake, some states such as Minnesota and Ohio have designated phosphorus sensitive areas (Hoag and Roka, 1994, p.185).

[9] The related information on manure generation and manure storage design were adapted from Christensen (1981) and Midwest Plan Service (1985), and the basic data for budgeting swine farm production activities and storage construction were obtained from Sutton, *et al.* (1994) and Oklahoma State Cooperative Extension Service (1995).

construction cost (TCC) function increases, the average construction cost (ACC) decreases while the marginal construction cost (MCC) is constant (Refer to Figure 3). Thus the range over the alternative size of production units considered is characterized by the presence of economies of size. This implies that swine waste management systems in Oklahoma give the larger sized operation to a more cost advantage.

TABLE 2 Derivation of Total, Average, Marginal Construction Costs and Economies of Size

Size of Operations	Construction Costs of Building and Storage			Economies of Size[2]
	Total Cost[1]	Average Cost	Marginal Cost	
100	21,061	300	89	0.70
300	39,006	219	89	0.59
500	56,951	203	89	0.56
700	74,896	196	89	0.55
900	92,941	192	89	0.54
1,200	119,758	189	89	0.53

Note: [1] The total annual depreciation cost of building and storage construction (TCC) was derived from the following regression equation: TCC = 12,089 + 89.27 × NUM_{SW}.
[2] The economies of size (SE) can be measured by the formula: SE = 1- MCC/ACC. The positive value of SE indicates the presence of economies of size.

The environmental regulations tested are based on the Oklahoma Feed Yard Act (OFYA) of 1996.[10] The key regulatory constraints tested were restraining application rates so they did not exceed the uptake levels of plant nutrients and so that manure storage capacity was adequate for the cropping system. (Table 3) provides an overall view of the regulatory framework. In the base situation

[10] The *Oklahoma Feed Yard Act* (OFYA) outlines the regulation and penalties for environmental pollution in swine waste management. The Act requires that the operator of the feed yard provides reasonable methods for the disposal of animal manure. In this act, the term "feed yard" is interchangeably used to a term "concentrated animal feeding operation (CAFO)". Any feedlot having over 2,500 heads of swine (weighing over 55 pounds) is required to obtain a CAFO permit.

without the environmental regulation, there is a manure storage capacity for a retention period of 90 days. The volume of this capacity represents a basic storage facility for a conventional swine operation. Two environmental scenarios are tested. Under the "regulation I"(less stringent regulation), the nitrogen application levels are limited to plant uptake. Under "regulation II" (more stringent regulation) manure application rates can not exceed nutrient uptake of either nitrogen or phosphorus.

TABLE 3 Environmental Regulations Considered for Swine Waste Management

Control Variables	Without Regulation	Regulation I	Regulation II
· Seasonal constraints for manure spreading[1]	depends on crop growing pattern	depends on crop growing pattern	depends on crop growing pattern
· Manure storage capacity			
- Retention period[2]	90 days	180 days	180 days
· Nutrient application[3]		application ≤ nitrogen uptake by crop	application ≤ nitrogen and phosphorus uptake by crop

Note : [1] Since it id difficult to apply manure to growing crop, land application must be made by seasonal constraint. This constraint is not exactly related to environmental regulation, but there exists a constraint for winter season in applying the manure to the land due to a leaching problem.

[2] According to the OFYA Rules (35:30-35-9: Duties of Owners and Operators - b), "retention structures shall contain 21-day storage of process wastewater plus the 25-year, 24-hour storm event." That is, the operators must consider a minimum safety or freeboard level required for 25-year rainfall event.

[3] According to the OFYA Rules (35:30-35-9: Duties of Owners and Operators -e-2-F- IX-bb), "when irrigation disposal of wastewater is used, facilities shall not exceed the nutrient uptake of the crop coverage or planted crop planting with any land application of wastewater and/or manure. Land application rates of wastewater should be based on the available nitrogen contents, however, where local air quality is threatened by phosphorus, the license should limit the application rate to current recommendations in NRCS Waste Utilization Standard 633 (or its current replacement)". Thus, land application rate of manure disposal should be based on the nutrient uptake of crop. The levels of nutrient uptake depend on the crop types and yield of crop production.

The LP model was solved by the GAMS program (General Algebraic Modeling System) which is an optimization software. The analytical results of the baseline are summarized in (Table 4). In this preliminary model, the manure handling system was an anaerobic storage facility which consists of a manure pit for storage until the waste can be applied to the land surface and incorporated into the soil by cultivation. The optimal value of the objective function (i.e, net return) without any regulation is estimated to be $377,144. Under "Regulation I" and "Regulation II", the optimal values of the objective functions are calculated to be $249,173 and $125,390, respectively. The differences of the optimal objective values in the scenarios are mainly because of the impact of nutrient restraints on the size of the swine production facility. Without any environmental restriction, an optimal decision for a producer would be to build the maximum size of swine production unit (1,200 sows) and irrigate 256 acres for corn. Manure storage capacity is constructed in a the six month period while corn is growing. Application of both nitrogen and phosphorus exceeds the crop uptake of those nutrients. Wheat was not competitive because of a combination of lower returns and lower nutrient requirements than those of corn. The shadow prices listed in the table represent the amount by which the objective function would be increased or decreased if the constraints were relaxed by one unit.[11] Shadow prices for both nitrogen and phosphorus are zero because there is a surplus of these nutrients.

Under "Regulation I" (nitrogen application rate cannot exceed plant uptake), the size of the production unit was reduced to 699 sows. Manure storage capacity is sufficient for six months. Nitrogen application (269 pound per acre) after adjustments for leaching and volatilization equals 240 pounds required for each acre of corn. Phosphorus application rates of 274 pounds exceed the 100 pounds required.

[11] The shadow prices estimate forgone returns due to compliance with manure application restrictions. The positive value of shadow price indicates that there is still more cost-saving opportunity to substitute swine manure nutrients for commercial fertilizer nutrients. The negative value of shadow prices indicates that the swine producer has surplus manure under the regulatory rules, and increasing one unit of manure produced has decreased net income by the amount of the shadow price.

TABLE 4 Baseline Results for Optimal Swine Waste Management - 256 Acre of Irrigated Land

	Without Regulation	Regulation I	Regulation II
Optimal value of objective function ($)	377,136	249,173	125,390
Size of sow operation (head)	1,200	699	260
Manure storage capacity (ft^3)	235,200	136,881	50,966
Manure applied to corn (ft^3/acre)	1,836	1,069	398
Corn producing land (acre)	256	256	256
Expected yield of corn production (bushel/acre)	180	180	180
Nitrogen uptake level (pound/acre)	240	240	240
Manurial nitrogen applied (pounds/acre)	440	256	95
Nitrogen fertilizer purchased (pounds/acre)	0	0	145
Phosphorus uptake level (pound/acre)	100	100	100
Manurial phosphorus applied[1] (pounds/acre)	467	272	101
Shadow prices of farm land ($/acre)	277	973	490
Shadow price of soil nitrogen ($/pound)	0	-2.98	0.29
Shadow price of phosphorus fertilizer ($/pound)	0	0	-2.84
Excess nitrogen applied (pounds/acre)	200	16	0
Excess phosphorus applied (pound/acre)	367	172	1.00
Ratio of animal size versus land	4.69	2.73	1.02

Note: [1]Application rates exceed uptake level because of field losses between time of application and plant uptake.

Under "Regulation II" (application rates for either nitrogen or phosphorus cannot exceed plant uptake) the size of the production unit was further reduced to 260 sows. Manure storage capacity is sufficient for six months. Nitrogen application (100 pound per acre) after adjustments for leaching and volatilization is not enough for uptake level of 240 pounds required for each acre of corn. Commercial nitrogen fertilizer (150 pounds per acre) would then be purchased to supply the remaining nitrogen requirements for corn production. Phosphorus application rates of 102 pounds (before adjustment for field loss) meet the 100 pounds required level.

In evaluating the impacts of environmental regulations on swine operation, it is found that crop land is a critical factor for swine waste management, as expected. Without regulations on fertilizer application rates, an acre of irrigated land is worth $277 for the purpose of producing corn. Under "Regulation I" the value of land increases to $973 per acre. The marginal value of land is derived from corn production plus its value for waste disposal. The negative shadow price on nitrogen means that the producer could pay up to $2.98 to dispose of one more pound of nitrogen which would allow the swine enterprise to expand. Under "Regulation II", an additional acre of land would add $490 to the objective function. The value of land is derived from corn production and phosphorus disposal. The producer could pay $2.84 to dispose of one more pound of phosphorus but nitrogen which is purchased at the margin so additional land is worth less than under "Regulation I". The results show that optimal resource allocation is quite sensitive as to whether regulations are imposed on nitrogen only or on both nitrogen and phosphorus. In order to analyze the effect of changing the irrigated land acreage, the sensitivity analysis was conducted with the irrigated land of 512 acre, as presented in (Table 5). The interesting result is that the analytical impacts of "Without Regulations" and "Regulation I" are the same if the irrigated land acreage is doubled in size. The result implies that the nitrogen loading restriction is not very effective on swine production operation if the size of land acreage for manure application is enough. In both cases the ratio of animal size versus land was shown in 2.34. So, the ratio of animal size versus land could be used as an animal density indicator in formulating the environmental regulation on swine waste disposal.

TABLE 5 Sensitivity Results for Optimal Swine Waste Management – 512 Acre of Irrigated Land

	Without Regulation	Regulation I	Regulation II
Optimal value of objective function ($)	432,239	432,239	245,887
Size of sow operation (head)	1,200	1,200	520
Manure storage capacity (ft^3)	235,126	136,881	101,932
Manure applied to corn (ft^3/acre)	918	918	398
Corn producing land (acre)	512	512	512
Expected yield of corn production (bushel/acre)	180	180	180
Nitrogen uptake level (pound/acre)	240	240	240
Manurial nitrogen applied (pounds/acre)	220	220	95
Nitrogen fertilizer purchased (pounds/acre)	29	29	155
Phosphorus uptake level (pound/acre)	100	100	100
Manurial phosphorus applied[1] (pounds/acre)	234	234	101
Shadow prices of farm land ($/acre)	203	203	490
Shadow price of soil nitrogen ($/pound)	0.29	0.29	0.29
Shadow price of phosphorus fertilizer ($/pound)	0	0	-2.74
Excess nitrogen applied (pounds/acre)	0	0	0
Excess phosphorus applied (pound/acre)	134	134	1
Ratio of animal size versus land	2.34	2.34	1.02

Note: [1]Application rates exceed uptake level because of field losses between time of application and plant uptake.

In reality, actual regulations on manure application rates to land vary between states. Oklahoma rules limit nitrogen application rates to the amount taken up by the crop unless there is a water quality problem with respect to phosphorus, in which case phosphorus application rates are also limited. That means the environmental regulation on only the nitrogen uptake level in manure application does not have as much effect on the size of operation as do regulations on the amount of phosphorus applied. However, this is somewhat of a gray area since soils do have some ability to assimilate excess phosphorus. Currently, the regulatory instrument in the OFYA is based on the command-and-control approach in implementing the standard-based objectives. In solving the environmental problems, many economists have been critical of a technology-based standard approach since the designated standard is not based on the criteria of an allocative efficiency. The economists suggest the market-based instruments such as taxes, subsidies, and pollution permit system. Basically, the incentive-based approach requires considerable information on both marginal external cost function and marginal social benefit function in controlling swine wastes. Given these accurate information, the optimal levels of taxation, subsidy, and trading permit are set at the amount of the MEC at the efficient output level (ensures that MSC=MSB), as shown in (Figure 2). However, it is unrealistic to expect that either the marginal external cost or marginal benefit functions are known with sufficient accuracy to calculate optimal level of taxation. Instead, economists have suggested a second-best approach. As an illustrated example, consider the nitrogen pollution problem in this swine production area. A local nitrate problem results whenever the applied nitrogen is not taken up by the plant and reaches groundwater aquifers, or is lost in surface runoff. In order to reduce the nitrate pollution problem, the effluent tax of nitrogen in applying the swine waste to land. As shown in (Table 4) and (Table 5), there are no excess nitrogen given with and without regulations in all cases of scenarios. In this case, the shadow price of soil nitrogen could be used as a proxy of the effluent tax required to achieve the given plant uptake level in nitrogen discharge. Theoretically, the tax rate on nitrogen discharge per pound could be imposed 0.29 dollar.

V. Conclusions

The analysis in this paper suggests the linear programming using the enterprise budgeting data can be used as a research tool to investigate the interrelationships in a representative swine producer, and to estimate the effect of a change in any one component on the rest of the enterprises. Swine producers under the environmental regulatory framework continuously seek to use their limited resources in the most profitable manner. The linear programming solutions based on the steady-static framework can provide the estimates of the optimal resource allocation and the potential impacts of proposed changes in nutrient loading restrictions in land application. The results indicate that impacts of regulatory restrictions on individual resources or pollutants can vary widely. A swine producer without environmental regulation will choose the cheapest method for waste handling such as excessive rate of land application and/or dumping. Under the control of environmental regulations, swine waste management system designed to enhance an environmental quality need more investment cost for handling facility. Very high shadow prices on nutrient disposal point out the need to find more cost effective methods of waste disposal and to better quantify the marginal externality or damage cost caused by the pollutant. The impact of environmental regulation on the level plant nutrient uptake depends on the specific type of nutrients. However, this study was only considered as the waste management system which consists of manure pit and irrigation system by the traveling gun. Thus, further work should be done to encompass several waste management alternatives for a comprehensive analysis of waste management systems. Finally, it should be noted that the results obtained from analyzing the linear programming model is significant only when complete fundamental information and data are available and reliable.

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