Farm Return and Land Price Effects from Environmental Standards and Stocking Density Restrictions

Alfons Weersink, Greg deVos, and Peter Stonehouse

This study assesses the economic and environmental effects to hog finishing farms from residual taxes/standards and restrictions on manure application and stocking density. Economic effects are measured in terms of net farm income and land prices, while levels of ammonia and excess nitrogen and phosphorus proxy the environmental effects. Any environmental policy requiring the need for additional land comes at a small cost to farmers who have access to adequate neighboring land. If this is not the case, then manure application and stocking density restrictions are expensive since the producer is basically forced to either purchase land or reduce hog production levels.

Key Words: land value, manure application restrictions, stocking density

Public concerns over the environmental consequences of livestock production and the concentration of that production in larger farm units has led to more numerous, and increasingly more stringent, regulations on farm practices. These regulations have evolved from simple ex ante restrictions, such as minimum separation distances of new barns from waterways, to ex post controls or incentives on management practices. Although there is a geographical disparity in the extent of the legislation among countries and jurisdictions (Beghin and Metcalfe, 2000), nutrient management standards and/or stocking density restrictions are becoming part of the regulatory constraints facing livestock farmers. For example, confined animal feeding operations (CAFOs) in the United States will not be able to spread manure at a rate greater than the crop nutrient demands. Similarly, many Canadian livestock farmers will be required to have in place a nutrient management plan (NMP) that includes a verification of stocking density to ensure nutrient standards are not exceeded, as well as an indication of how nutrients are to be monitored and applied.

The restrictions will come at a cost to farmers, as several studies have concluded that the disposal expenses of manure outweigh its nutrient value as a replacement for purchased fertilizers (Boland et al., 1999; Boland, Preckel, and Foster, 1998; Roka and Hoag, 1996). For example, Schnitkey and Miranda (1993) found that restrictions of phosphorus application reduce hog numbers by approximately the same percentage as the reduction in required phosphate runoff. Den Ouden (1997) estimated the direct cost of regulation in the Netherlands to be between 5% and 10% of the average total cost of hog production, and similar estimates of approximately \$2–\$5 per hog cost increases associated with nitrogen application standards were obtained by Lauwers, van Huylenbroeck, and Martens (1998). Fleming and Long (2002) estimated average net farm revenue would fall by 7% if manure can only be applied on land with slopes of less than 12%. The impacts of land availability prominent in proposed environmental legislations were not addressed by these studies.

Recent papers by Kaplan, Johansson, and Peters (2004), and Johansson and Kaplan (2004) examine the implications of land constraints of manure application at the regional and sector levels in the United

Alfons Weersink is professor, Greg deVos is former graduate research assistant, and Peter Stonehouse is professor, all in the Department of Agricultural Economics and Business, University of Guelph, Ontario, Canada. This paper was completed while Weersink was a Henry Schapper Fellow with the School of Agricultural and Resource Economics at the University of Western Australia.

The authors gratefully acknowledge the helpful comments of three anonymous journal reviewers and the financial support provided by the Ontario Ministry of Agriculture and Food and BIOCAP/SSHRC.

States, while Vukina and Wossink (2000) estimated the increase in Dutch land prices in regions where a manure quota restriction was binding. These studies show the price effects of land constraints and the regional variation in impacts, but do not examine how individual operators would respond to application restrictions under alternative conditions. Using survey data on land availability, manure levels, and application rates for U.S. swine farms, Ribuado, Gollehon, and Agapoff (2003) found that most hog farmers apply their livestock waste at levels greater than the needs of a nitrogen-based (N-based) or phosphorus-based (P-based) nutrient management plan. Meeting the requirements of a nutrient standard would require large farms to find significant amounts of land (particularly for a P-based standard), but the costs of acquiring such land were not addressed by Ribuado, Gollehon, and Agapoff (2003).

Previous studies have not provided a comprehensive assessment of the changes in all major residuals from hog farms [ammonia and excess nutrients (nitrogen and phosphorus)] and farm abatement costs prompted by the major types of manure legislation. This study develops a theoretical and empirical model to examine the farm-level effects on returns, land values, and residuals from pending application and stocking density restrictions. While farmers can change rations and handling systems in response to policy efforts, it will be demonstrated in this analysis that the financial impacts depend significantly on the availability of land for manure disposal.

The objective of this study is to assess the economic and environmental effects to hog finishing farms from residual taxes/standards and restrictions on manure application and stocking density. In the following section, a theoretical model is presented which determines the shadow values of manure and land along with the effects of environmental policies on those values. We then outline the optimization model used to determine the producer choice of management system with each policy and the associated residual levels. The model is based on a hypothetical hog finishing farm in the livestock-intensive region of southwestern Ontario where the geographic conditions are similar to states in the U.S. Great Lakes region. In the next section, the effects of taxes/standards on ammonia, excess nitrogen, and excess phosphorus, together with restrictions on manure and stocking density, are evaluated in terms of net farm returns, residuals, and land prices. The paper concludes with a discussion of the policy implications.

The Theoretical Model

The Base Model

To illustrate the effects of manure legislation, we will assume a static model for a representative hog finishing operation that produces hogs (H).[1] These pigs can be sold at a net price of p_h, representing the difference between the selling price of hogs and the purchase price of feeder pigs. The farmer also raises a crop which is sold and then bought back for feed for a net selling price of p_c. The yield of the crop is a function of the nutrients applied (n), $Y(n)$. Nutrients are provided from either inorganic sources of commercial fertilizer (f) purchased at price p_f, or from manure (m), so that $n = m + f$. Crop-available nutrients in the manure (m) are a linear function of the application rate of manure (a) and a factor converting manure volume to the amount of fertilizer that can be used by the crop (n_l), $m = n_l a$. The amount of manure produced on the farm (M) is the product of hog output and the volume of manure produced per pig, α ($M = \alpha H$). The cost of raising pigs, including manure handling, is given by the function $C(\alpha H)$, which is assumed to increase at an increasing rate. The per hectare cost of manure application, p_a, is constant regardless of the application rate (a) and the number of hectares on which manure is applied (L). The farmer must apply the total volume produced by the hogs (M) on available cropland ($M = aL$). Land can be obtained at a rental rate of r per hectare, but only $L_{\max}$ is available.

The producer is assumed to maximize net returns from livestock and crop production through the choice of hog numbers, manure and commercial fertilizer application rates, and land area subject to the constraints of manure disposal and available land. The problem can be formally stated through the following Lagrangean equation (ζ) obtained after substitution for the various identities:

$$(1)\quad \zeta(H, a, f, L) = \text{Max } p_h H + p_c Y(n_l a + f)L - C(\alpha H) - p_a aL - p_f fL - rL + \mu(\alpha H - aL) + \lambda(L_{\max} - L).$$

The respective Kuhn-Tucker first-order conditions for the choice variables (H, a, f, L) are:

$$(2)\quad \left[p_h - C_H + \mu\alpha\right]H = 0,$$

[1] Innes (2000) has developed a spatial, theoretical model to explore the efficiency effects of scale regulations, taxes, and handling standards with three environmental effects (spills, runoff, and direct ambient pollution).

$$(3)\quad \left[(p_c n_l Y_n - p_a - \mu)L\right]a = 0,$$
$$\mu\left[\alpha H - aL\right] = 0,$$

$$(4)\quad \left[(p_c Y_n - p_f)L\right]f = 0,$$

$$(5)\quad \left[p_c Y - p_a a - p_f f - r - \mu a - \lambda\right]L = 0,$$
$$\lambda\left[L_{\max} - L\right] = 0,$$

where μ is the shadow value of manure and λ is the marginal value of an additional hectare.

Optimal hog production (H^*) is found through equation (2), where marginal revenue (p_h) less marginal cost (C_H) is equal to the shadow price of manure on a per hog basis. Assuming an interior solution ($H^* > 0$), the manure shadow price is given by:

$$(6)\quad \mu = -(p_h - C_H)/\alpha.$$

Note, μ is negative and represents the implicit cost of disposing of manure. It increases in absolute terms with hog price and with decreases in the amount of manure produced by an individual pig.

The optimal application rate of manure is found by solving equation (3) explicitly for a. At this rate, the marginal benefit of increased crop yield less application cost is equal to the shadow value of manure. Since μ is negative, it is possible for a profit-maximizing farmer to apply manure at a rate such that its marginal product is negative ($Y_n < 0$) if the cost of disposal is too great. Whether a farmer uses commercial fertilizer and/or manure for crop nutrient needs depends on comparing the net marginal value of the two inputs. Assuming $p_a - \mu$ is less than p_f, it is possible for the marginal value of commercial fertilizer to be greater than its marginal input cost and still not be used ($f = 0$). Schnitkey and Miranda (1993) develop a model where the choice between manure and commercial fertilizer application in a given field depends on the distance of that field from the livestock facility. However, in this model, the application rate associated with optimal hog production will be equal to $\alpha H^*/L$, so that some manure will be applied on all land with any deficit nutrient needs covered by inorganic fertilizer.

Land will be rented until the marginal benefits of growing crops ($p_c Y$) and disposing of the manure ($-\mu a$) are equal to the per hectare costs of organic and/or commercial fertilizer application and the market rental rate [equation (5)]. The marginal value of an additional unit of land is given by:

$$(7)\quad \lambda = \left[p_c Y - p_a a - p_f f - r - \mu a\right].$$

Thus, the shadow value of land increases with an increase in the implicit cost of manure disposal (increases with the marginal returns to hog production) and increases in net crop returns per land unit.

Manure Application Restrictions

Residuals into the environment from livestock-crop production are assumed to be associated with the application of nutrients beyond the requirements of the crop. In an effort to reduce excess nutrient loadings, many regions have implemented maximum application rates on either the volume of manure or the amount of a given nutrient that can be applied. Assuming the producer in the above model faces a constraint on the amount of manure that can be applied per hectare ($a_{\max}$), the first-order conditions are modified to:

$$(3')\quad \left[(p_c n_l Y_n - p_a - \mu)L - \nu\right]a = 0,$$
$$\nu(a_{\max} - a) = 0,$$

where ν is the marginal cost to the producer of the application restriction. Assuming the application constraint is binding so that the restriction is less than the profit-maximizing rate in the original problem ($a^* > a_{\max}$), ν is positive. If all available land is rented, the restriction implies the number of hogs must be reduced from the previous scenario in order to meet the constraint on manure volume equaling the amount spread.

The effect of the reduced application rate on the marginal value of land can be seen by evaluating equation (7) under a^* and $a_{\max}$. The difference depends on the shadow value of manure. The restriction forces a reduction in optimal hog numbers (if there is not enough available land to spread the volume of manure generated), and thereby increases the net marginal return to raising hogs. Thus, the shadow value of land is directly related to the implicit cost of manure disposal. Note the deterministic nature of the model implies a tax rate on manure application of ν associated with a^* will result in the desired reduction in application rate.

Stocking Density Restrictions

Another increasingly common restriction imposed on hog farmers is that there is a fixed amount of land available for each animal unit produced. Imposing a constraint on the stocking density ($SD = H/L$) of

SD_{max} on the base model, the first-order conditions are modified to:

$$(2') \quad [p_h - C_H + \mu\alpha - \delta/L]H = 0, \quad \delta(SD_{max} - H/L) = 0,$$

$$(5') \quad [p_cY - p_a a - p_f f - r - \mu a + \delta(H/L^2) - \lambda]L = 0, \quad \lambda[L^* - L] = 0,$$

where δ is the marginal cost of the stocking density restriction. The marginal value of land with the restriction increases to:

$$(7') \quad \lambda = [p_cY - p_a a - p_f f - r - \mu a + \delta(H/L^2)].$$

The increase in the shadow value of an additional hectare of land associated with the restriction will increase with hog numbers and decrease with the amount of land available.

The Empirical Model

The extent of the impacts of the alternative environmental policy instruments suggested by the theoretical model is evaluated on a typical hog finishing operation using an optimization model developed by Stonehouse, deVos, and Weersink (2002). The model is based on conditions for a swine farmer in the livestock-intensive region of southwestern Ontario that is similar to the physical environment in Great Lake states such as Michigan and Ohio. The number of pigs on farms in Ontario has risen steadily over time to its current level of 3.7 million, with much of the total exported. Cash sales from pig farms represent approximately 10% of total farm receipts for the province.

The empirical model incorporates several complexities not included in the theoretical model of the previous section. First, several residuals with significant environmental impacts are considered: ammonia, excess nitrogen, and excess phosphorus. The former is associated with climate change and odor, while the latter two residuals contribute primarily to water quality deterioration in the form of eutrophication and hypoxia. Second, the level of these residuals can be altered by the choice of practices such as feeding ration, manure storage, and application method. In addition, there are potential tradeoffs among the level of residuals between systems since those that reduce ammonia through volatilization will increase the level of nitrogen (N) in the manure, and thus potential excess N. Tradeoffs between N and P are discussed in Leneman, Giesen, and Berentsen (1993).

The objective of the model is to maximize farm returns net of the costs and values of handling and utilizing the manure produced through the choice of manure management system, hog production levels, fertilizer purchases, land rentals, crop production and sales, and feed purchases. Mathematically, the objective function is specified as:

$$(8) \quad \text{Max}\ \pi = p_hH - p_mM - \sum_{i=1}^{81} p_{ms,i}MS_i - \sum_j c_jA_j - \sum_j \sum_k p_{f,k}F_{j,k} - \sum_k p_{mn,k}MN_k - p_{NH}NH - \sum_k p_{en,k}EN_k - p_lL + \sum_j p_{c,j}Y_j,$$

where p_h is the net price per hog produced (H), M is the volume of manure with a potential price (or cost) of p_m, $p_{ms,i}$ is the annualized cost of manure handling system (MS) i, A_j is the area allocated to crop j (j = corn and soybeans), c_j is the cost per hectare of growing crop j, $p_{f,k}$ is the price of inorganic fertilizer of nutrient k (k = nitrogen and phosphorus), $F_{j,k}$ is the amount of nutrient k purchased for use on crop j, MN_k is the amount of nutrient k available from manure with a potential price of p_{mn}, NH is the amount of ammonia lost with a price of p_{NH}, EN_k is the amount of nutrient k above crop needs lost to the environment at a price of p_{en}, L is the amount of neighboring land available to apply manure at a cost of p_l, and Y_j is the output of crop j sold at a price of $p_{c,j}$.

Choice variables include the number of hogs finished and the manure handling system. There are 81 possible systems (MS) based on a combination of each of three possible alternatives for feeding, collection, storage, and application. Feed ration choices include a base corn-soybean meal ration, a second that adds lysine, which can replace some of the crude protein in the ration and subsequently reduce the level of nitrogen in the manure, and a third that adds phytase. Phytase reduces phosphorus residuals in hog manure by enabling the hogs to better utilize P in grain, thereby reducing the need to add di-calcium phosphate to feed. Low-phytic acid corn may also serve to reduce excess P levels, but was not considered in the model.

The three collection methods for the liquid manure are (a) by gravity through fully-slatted floors, (b) through partially-slatted floors to below-floor temporary storage (flush gutter), or (c) by scraping of solid concrete floors to storage. The three storage choices are (*a*) an earthen pit (lagoon), (*b*) an above-ground, open-topped concrete tank, or (*c*) an above-ground, covered concrete tank. The field application of manure is either by (*a*) an irrigation gun, (*b*) a tanker broadcaster, or (*c*) a tanker injector. These activities are included in the optimization model as integer variables.

The remaining choice variables in the model are specified as real number activities. In addition to hog numbers, the farmer must choose what crops to grow and whether the nutrient needs for these crops are provided from the manure and/or synthetic fertilizers. Tillable land can be used to grow corn and/or soybeans, each of which can be sold at market prices. While corn can be retained for feeding, soybeans must first be sold and then purchased back as soybean oil meal. Any necessary supplemental feed purchases such as soy meal are at market prices.

Constraints on the model include a limit on the number of hogs produced ($H \le H_{max}$). The representative farm is assumed to finish 1,000 hogs per 100-day hog finishing cycle ($H_{max} = 3{,}000$ annually). Total manure produced per annum is a function of hog production and volume of manure produced per hog, α ($\alpha H = M$). The nutrient composition of manure is a function of the feed ration, as well as starting and finishing weights of the pig. The level of nutrients in the manure depends on the excretion rates of nutrients and the losses associated with each manure system. For example, gaseous nitrogen losses in the form of NH_4 from volatilization will be higher with an earthen pit than other storage systems and result in lower N levels in the manure to be applied. The constraints on nutrient availability in the manure can be expressed as

$$\sum_k n_{k,i} MS_i = MN_k,$$

where $n_{k,i}$ is the amount of nutrient k in a crop-available form in manure associated with system i. The levels of manure produced, its nutrients composition and availability, and volatilization rates are estimated for alternative systems using MCLONE4, which is a computerized decision support tool for manure management in Ontario conditions (Manure Systems Research Group, 1999).

The manure residuals estimated for each system are gaseous ammonia, along with excess nitrogen and phosphorus applied to cropland. Volatilization is predicted through the constraint

$$\sum_i nh_{l,i} MS_i = NH,$$

where $nh_{l,i}$ is the amount of ammonia emitted with manure system i. Crop nutrient balancing restrictions ensure that crop needs are met through manure application or from inorganic fertilizer purchases, and also allow the quantities of excess nutrients to be measured. Nutrient transfer restrictions can be summarized by:

$$(9) \quad -MN_k + \sum_j f_{k,j} A_j - f_k L + F_k - EN_k = 0,$$

where $f_{k,j}$ is the optimal application rate of nutrient k to crop j, and f_k is the application rate of the nutrient to additional land requirements. In some situations, there is no additional land available and all manure must be applied on the given land base. When nutrient needs of the crop are not met through manure application, supplementary inorganic fertilizer can be purchased at market cost.

Manure application rates are assumed to be set so as not to exceed a maximum loading rate, which will depend on crop grown (10 m^3 per hectare for soybeans and 20 m^3 per hectare for corn) as specified in provincial guidelines (Ontario Ministry of Agriculture, Food, and Rural Affairs, 1999). The amount of land for manure disposal—which is confined to the spring, and feed crop production purposes—is assumed to be 40 hectares. This land area is typical for a hog farmer finishing 3,000 hogs annually, and also allows for all manure to be disposed at the assumed loading rates. When the model makes neighboring land available, it can only be used for manure disposal at a fixed cost. The model was constructed in Microsoft Excel, and further details on the structure and parameter values are found in Stonehouse, deVos, and Weersink (2002).

Results

Base Systems

The profit-maximizing model involved a manure management system of a corn-soybean meal ration with lysine, solid flooring, an earthen pit storage, and irrigation application. Net farm returns to labor, management, and land are $123,596 (Can.), and the residual levels for ammonia and excess nutrients are reported in tables 1 and 2. The second-order conditions are satisfied, as each of the 81 potential farm management systems were evaluated individually. The resulting unique optimal system involves operating at full hog production capacity, planting all available land to corn, disposing of all hog manure solely on this ground, selling all corn,

Table 1. Effects of Ammonia Taxes/Restrictions on Farm Returns and Ammonia Levels for Two Hog Farming Systems

		Ammonia Tax ($/kg)			
System	Measure	0	20	30	40
Most Profitable [a]	Net Farm Returns (Can$)	123,596	22,080	17,937	17,937
	Ammonia Lost (kg)	5,143	3,403	0	0
	Herd Reduction (%)	0	34	100	100
Typical [b]	Net Farm Returns (Can$)	116,218	48,618	15,193	10,559
	Ammonia Lost (kg)	3,380	3,380	2,236	0
	Herd Reduction (%)	0	0	34	100

[a] Most profitable manure management system involves corn-soybean meal ration with lysine, solid flooring, earthen pit storage, and irrigation application. Manure can be disposed on 40-hectare land base which grows all corn for sale and purchases all hog feed.

[b] Typical system is same as most profitable system above, except fully-slatted floors and concrete sealed storage.

Table 2. Effects of Excess Nutrients Taxes (Manure Application Restrictions) on Residual Levels and Farm Production for Two Hog Farming Systems

		Excess N		Excess P				
System	Rental Land Available	Tax Rate ($/kg)	Level (kg)	Tax Rate ($/kg)	Level (kg)	Land Rented (ha)	Herd Reduction (%)	Net Returns (Can$000s)
Most Profitable [a]	Base	0	1,060	0	1,023	0	0	123.6
	Yes	0.10	0	0	476	12.3	0	123.5
		0	0	0.19	476	12.3	0	123.4
		0	0	1.62	0	23.0	0	122.7
	No	16.64	0	0	476	n/a	18.1	105.9
		0	0	32.26	476	n/a	18.1	90.6
		0	0	33.68	0	n/a	33.8	89.9
Typical [b]	Base	0	1,469	0	1,023	0	0	116.2
	Yes	10.09	0	0	314	15.9	0	116.1
		0	0	0.19	314	15.9	0	116.0
		0	0	1.72	0	23.0	0	115.5
	No	15.56	0	0	314	n/a	23.4	93.3
		0	0	32.26	314	n/a	23.4	88.2
		0	0	33.78	0	n/a	33.8	82.7

[a] Most profitable manure management system involves corn-soybean meal ration with lysine, solid flooring, earthen pit storage, and irrigation application. Manure can be disposed on 40-hectare land base which grows all corn for sale and purchases all hog feed.

[b] Typical system is same as most profitable system above, except fully-slatted floors and concrete sealed storage.

and purchasing all hog feed requirements separately from suppliers. The farmer's shadow price on an additional hectare of land is $761.79 with this system. Using a discount rate of 10%, the corresponding bid price for land is $7,617.90 per hectare ($3,047.16 per acre), which is around the average price for farmland in the livestock-intensive region of southwestern Ontario during the year 2000 time period on which the parameter values were originally based. This is an indicator that the parameters assumed, including the land base chosen for the hypothetical hog farm in this study, are appropriate.

Alternative manure management systems have differing levels of farm returns and residuals. Consequently, the effects of environmental legislation on profitability and residuals will vary depending upon the system the farmer presently has in place. Thus, in addition to the profit-maximizing system, a typical hog finishing operation is also examined. This system involves the same feed ration and application method but with fully-slatted floors and a covered, concrete storage. Farm returns are 6% less ($116,218 vs. $123,596), but emission levels vary depending on the residual. Ammonia levels are more than 50% greater, while excess N levels are approximately 30% less for the profit-maximizing system than the typical one (see tables 1 and 2). Excess P levels are the same for both systems. The tradeoffs between income and residual levels for these two manure handling systems, together with others, are fully discussed in deVos, Weersink, and Stonehouse (2003), as is the sensitivity of the optimal farm management practices to prices. Inferences on the effects of manure legislation for alternative farming systems are drawn from the relative effects on these two farm types.

Residual Restrictions

The effects of manure application restrictions are considered in terms of restrictions on the levels of excess residuals, which are assumed to be deterministically related to application levels. The deterministic assumption also implies that the restrictions can be viewed either through a direct standard or through a residual tax.

Reducing the amount of nitrogen lost to the atmosphere can be accomplished easiest by moving to an application system that injects the manure directly into the soil as opposed to spreading the manure by an irrigation gun. The cost and ammonia levels for the three application methods considered are negatively correlated. The difference in costs between irrigation and broadcast is approximately \$0.05 per hog, and between broadcast and injection is \$0.15 per hog. Since 1 kg is the average amount of ammonia produced per hog marketed annually across all handling systems, a small ammonia tax will cause a shift between application systems. Moving from irrigation to injection reduces total ammonia levels by approximately 300 kg (10% of total) for a farm marketing 3,000 hogs annually, depending upon the handling system. Further ammonia reductions must generally come by reducing the total quantity of manure produced and not the application rate. This result has significant effects on profit, as shown by the large decreases in net farm returns compared to the base scenarios for the two farming systems with an irrigation-based application method (table 2).

As smaller quantities of ammonia are emitted from a manure system initially, higher effective tax rates are required in order to provide the incentive to reduce these residuals. For example, a tax of \$32.29 per kg of ammonia emitted would be required to reduce ammonia residuals to zero by a farmer operating under a typical manure management system. In contrast, a tax of \$21.16 per kg of ammonia emitted is necessary to impose the same reduction on a farmer operating under the system maximizing farm returns. If less ammonia is emitted initially, a farmer will value these units more at the margin and will require a higher tax level to provide the necessary incentive to cut back hog production.

Farmers with systems generating less ammonia may not reduce herd levels with an ammonia tax. For example, if a per unit ammonia residual tax of \$20 per kg was charged, the most profitable system would cut annual hog production by approximately 34% at a cost of over \$100,000. Total ammonia levels emitted by this system would consequently fall to 3,403 kg annually, which is still higher than the base scenario under the typical management system (3,380 kg) (table 1). With an ammonia tax of \$20 per kg, production levels, and thus ammonia levels, would not change under this common system, but net returns would be reduced by the amount of tax paid (20 × 3,380).

The effects of regulations targeted to excess nutrients (i.e., manure application restrictions) are shown in table 2 for the two systems. The base scenario is initially given for each, followed by the excess N tax to reduce its residual level to zero, followed by the excess P tax to do the same, and then the excess P tax rate to lower excess P residuals to zero. These rates (or restrictions) are determined assuming excess land can be obtained and when no land is available for manure disposal so that the reductions in residuals come through herd reductions.

As discussed earlier, the availability of neighboring land to apply manure is critical to the effects of the residual taxes on excess nutrients. For example, a tax of \$0.10 per kg of excess N is required to reduce applied nitrogen excesses to zero. At this rate or higher, the farmer bears the transportation cost associated with applying the total volume of manure associated with 3,000 hogs over a larger land base rather than pay the residual tax. An additional 12.3 hectares of land is sufficient to reduce excess N to zero at a cost of \$108 (0.1% of total net farm returns). Note that the tax of \$0.10 per kg of excess N has the same effect if the manure application rate was based on an N standard. Applying the manure over this larger land base reduces excess P levels to 476 kg, which can also be prompted with an excess P tax of \$0.19 per kg. A tax of \$1.62 per kg of excess P results in no excess nutrients as the farmer obtains 23 more hectares on which to apply the manure (table 2).

Eliminating excess nitrogen can still lead to excess P levels. The result that more land is needed to apply the same quantity of manure to meet a standard on excess P (or avoid paying a tax on excess P) than with an application standard tied to excess N is consistent with several other studies (e.g., Kaplan, Johannson, and Peters, 2004; Ribaudo, Gollehon, and Agapoff, 2003). Although additional distance costs to spread manure are not incorporated into this study (as done by Fleming, Babcock, and Wang, 1998), delivery costs will be higher with an excess P standard. Neither is the amount of phosphorus present in the soil from previous applications considered, so that the effects of the restrictions may be understated.

If no additional land is available to dispose of the manure, the farmer must meet the nutrient standards by decreasing hog production. A tax of $16.64 per kg of excess N is sufficient to cause the farm to reduce herd numbers by 18%, and consequently reduce excess N levels to zero. A tax of approximately $34 per kg of excess P is required to eliminate excess P. This tax forces a 34% reduction in herd numbers and an approximately 30% reduction in net farm returns (table 2). The effects of the application restrictions are similar across the two systems. Note that gun irrigation is used to apply the manure under both systems considered. It is the cheapest of the three application methods and maximizes the amount of N lost to the atmosphere, and thus minimizes the amount of N in the manure.

Manure and Stocking Density Restrictions

Two forms of output controls are considered: manure/herd reductions of 25% and stocking density restrictions (see table 3). Since the manure systems assessed in this study do not alter the volume of manure (only its composition), the enforcement of manure volume restrictions is equivalent to setting limits on hog numbers. Thus, reducing herd numbers by 25% reduces the amount of ammonia produced by the same percentage for both systems. The profit-maximizing system therefore still remains as the system generating significantly more ammonia than the typical system listed in table 3. The 25% reduction in manure/herd reduces net returns by 21% for the typical system compared to 20% for the most profitable system that generates more ammonia. A blanket-type approach is therefore relatively more costly to farmers with less-polluting systems since they receive no preferential treatment for initially using better ammonia-containing management practices. The reduction in herd numbers is sufficient to eliminate excess N, but 267 kg of excess P remains present with both systems.

The stocking density restriction constrains production capacity to a maximum based on the available land base. In Ontario, the most common requirement is that enough land be available to apply manure at rates of a maximum of one animal unit per acre annually. One animal unit is equivalent to 15 marketed finishing hogs. Thus, the restriction of 37.5 hogs per hectare requires farmers to have 40 hectares of neighboring land in addition to their own in order to achieve their full hog production capacity. Such a policy will effectively reduce excess nutrient levels under both systems, while the amount of ammonia is not changed since the volume of manure remains constant. Shadow prices on additional units of land decrease only marginally to $558.09 per hectare with the decrease associated with the small assumed transport costs of manure to neighboring land.

The abatement costs would rise significantly if no extra land was available to the producer to meet the stocking density restriction of one animal unit per acre. Production levels would have to be cut by 50% in both systems, thereby reducing net returns by over 40% in each case. Applying less manure to the existing land base of 40 hectares would eliminate both excess N and P, while ammonia levels would fall by the same percentage as herd numbers (50%). Once land becomes a constraining resource on the amount of hogs that can be produced, its shadow price skyrockets to $4,301.10 per hectare ($1,720.44 per acre) for own land, and to $3,516.88 per hectare ($1,406.75 per acre) for neighboring land. The latter is the rental rate our hypothetical hog farmer would be willing to pay for the use of extra land that would be used only for manure disposal purposes. In the livestock-intensive regions of Ontario where stocking density restrictions were imposed by local authorities, farmland values have risen to approximately these values in the last three years. For example, land in parts of Huron and Perth counties has more than doubled to approximately $7,000 per acre, which is consistent with the values suggested in this study where stocking density restrictions are binding. Thus, when land is a limiting factor to production, marginal values placed on an extra unit can increase significantly. In addition, the attractiveness of entering one farm industry (hogs) can strongly impact other farm sectors through the bidding up of the price of farmland.

Table 3. Effects of Manure and Stocking Density Restrictions to Reduce Excess Nutrients on Production for Two Hog Farming Systems

System	Restriction	Ammonia (kg)	Excess N (kg)	Excess P (kg)	Net Farm Returns (Can $000s)	Added Land Required (ha)	Herd Reduction (%)
Most Profitable [a]	Manure (Herd)	3,857	0	267.1	98.9	0	25
	Reduction of 25%	5,143	0	0	119.7	40	0
	Stocking Density	2,572	0	0	72.3	0	50
Typical [b]	Manure (Herd)	2,535	0	267.1	91.8	0	25
	Reduction of 25%	3,380	0	0	112.5	40	0
	Stocking Density	1,690	0	0	65.1	0	50

[a] Most profitable manure management system involves corn-soybean meal ration with lysine, solid flooring, earthen pit storage, and irrigation application. Manure can be disposed on 40-hectare land base which grows all corn for sale and purchases all hog feed.

[b] Typical system is same as most profitable system above, except fully-slatted floors and concrete sealed storage.

Conclusions

This study has developed a simple theoretical model to illustrate the effects of environmental policies on the shadow values of manure disposal and land. It then empirically estimated the effects of these policies on farm returns and the levels of ammonia, excess nitrogen, and excess phosphorus. Residual standards/taxes that recognize the heterogeneity among producers can reduce residual levels at relatively low costs to producers. Those farmers emitting low levels of residuals may not need to adjust practices to meet the standards, while those generating higher levels will have to adjust their manure handling. However, the standards on ammonia and excessive nitrogen cannot be met by a single system without reductions in hog numbers or increases in available land. Systems that reduce volatilization will subsequently increase the nitrogen content of manure, and thereby increase the likelihood of nitrogen levels from manure being above crop requirements. The industry-prescribed excess application limit of phosphate to land is high enough that it will not affect any manure management systems under farm conditions assumed for this study. This limit will only be breached in the most excessive soil phosphorus level conditions.

Farmer-owned land base and quantities of available neighboring land are the major factors influencing the effects of environmental policies on hog farms. These variables determine the hog stocking density of the operation, the total nutrient excesses applied to land, and the marginal value a farmer will place on additional units of land. Any environmental policy requiring the need for additional land comes at a small cost to farmers who have access to adequate neighboring land. The result assumes that the only cost incurred by the hog farmer is in the transportation of manure to this land, but the actual costs may be higher since crop producers do not fully substitute manure nutrients for inorganic fertilizer (as reported by Kaplan, Johannson, and Peters, 2004).

The major costs of the environmental policies examined here arise when no additional lands are available, since the primary option to reducing nutrient residuals is to cut back manure through a reduction in hog production. The predicted prices for the empirical model reflect actual changes in farmland prices for the most livestock-intensive regions of southwestern Ontario that have faced a local stocking density standard. Imposing this standard for all producers will increase the demand for farmland, with the extent of the increase dependent on the size of livestock production relative to available cropland. Thus, the implementation of stocking density restrictions common in current or pending legislation facing many livestock farmers could have significant individual and sectoral cost implications depending on land availability.

References

Beghin, J., and M. Metcalfe. (2000, 1st Quarter). "Market Hogs? An International Perspective on Environmental Regulation and Competitiveness in the Hog Industry." *Choices*, pp. 28–33.

Boland, M. A., K. A. Foster, P. V. Preckel, D. D. Jones, and B. C. Joern. (1999). "Using Linear Programming to Minimize Manure Storage and Application Costs in Pork Production." *Journal of Production Agriculture* 12(3), 405–482.

Boland, M. A., P. V. Preckel, and K. A. Foster. (1998). "Economic Analysis of Phosphorus-Reducing Technologies in Pork Production." *Journal of Agricultural and Resource Economics* 23(2), 468–482.

Den Ouden, M. (1997). "Economic Modelling of Pork Production-Marketing Chains." *Mansholt Studies*, No. 4, Wageningen Agricultural University, The Netherlands.

deVos, G., A. Weersink, and P. Stonehouse. (2003). "Economic-Environmental Tradeoffs in Swine Finishing Operations." *Canadian Journal of Agricultural Economics* 51(1), 55–68.

Fleming, R. A., B. A. Babcock, and E. Wang. (1998). "Resource or Waste? The Economics of Swine Manure Storage and Management." *Review of Agricultural Economics* 20(1), 96–113.

Fleming, R. A., and J. D. Long. (2002). "Measuring the Cost of Restricting Access to Cropland for Manure Nutrient Management." *Agronomy Journal* 94(1), 57–64.

Innes, R. (2000). "The Economics of Livestock Waste and Its Regulation." *American Journal of Agricultural Economics* 82(1), 97–117.

Johansson, R. C., and J. D. Kaplan. (2004, April). "A Carrot-and-Stick Approach to Environmental Improvement: Marrying Agri-Environmental Payments and Water Quality Regulations." *Agricultural and Resource Economics Review* 33(1), 91–104.

Kaplan, J. D., R. C. Johansson, and M. A. Peters. (2004). "The Manure Hits the Land: Economic and Environmental Implications When Land Application of Nutrients is Constrained." *American Journal of Agricultural Economics* (forthcoming).

Lauwers, L. H., G. van Huylenbroeck, and L. Martens. (1998). "A Systems Approach to Analyze the Effects of Flemish Manure Policy on Structural Changes and Cost Abatement in Pig Farming." *Agricultural Systems* 56(2), 168–183.

Leneman, H., G. W. J. Giesen, and P. B. M. Berentsen. (1993). "Cost of Reducing Nitrogen and Phosphorus Emissions on Pig Farms in the Netherlands." *Journal of Environmental Management* 39(1), 107–119.

Manure Systems Research Group. (1999). *MCLONE4: An Integrated Systems Approach to Manure Handling Systems and Nutrient Management.* University of Guelph, Guelph, Ontario, Canada.

Ontario Ministry of Agriculture, Food, and Rural Affairs. (1999). *Best Management Practices: Livestock and Poultry Waste Management.* Industry Handbook, OMAFRA, Toronto, Ontario.

Ribaudo, M. O., N. R. Gollehon, and J. Agapoff. (2003). "Land Application of Manure by Animal Feeding Operations: Is More Land Needed?" *Journal of Soil and Water Conservation* 58(1), 30–38.

Roka, F. M., and D. L. Hoag. (1996). "Manure Value and Live-weight Swine Decisions." *Journal of Agricultural and Applied Economics* 28(1), 193–202.

Schnitkey, G., and M. Miranda. (1993). "The Impact of Pollution Controls on Livestock-Crop Production." *Journal of Agricultural and Resource Economics* 18(1), 25–36.

Stonehouse, P., G. deVos, and A. Weersink. (2002). "Livestock Manure Systems for Swine Finishing Enterprises." *Agricultural Systems* 73(2), 279–296.

Vukina, T., and A. Wossink. (2000). "Environmental Policies and Land Values: Evidence from the Dutch Nutrient Quota System." *American Journal of Agricultural Economics* 26(4), 443–460.