Chapter 3
Water-Air Tradeoffs at the Farm Level

A farm-level perspective allows us to look at the economic decisions individual producers make to meet environmental goals, given previous management choices and farm characteristics. We examine the hog sector because it exemplifies the changes to scale, structure, and location that have occurred in the confined animal sector since the 1960s. In 1982, there were 175,284 farms with confined hogs, containing 6.3 million animals (USDA, ERS, 2005). By 1997, the number of farms had shrunk 64 percent to 63,723, while the number of hogs on these farms increased to 8.2 million (USDA, ERS, 2005). These larger facilities (in terms of animal units) are not necessarily larger in terms of cropland. Thus, 51 percent of the recoverable nitrogen (nitrogen remaining after manure handling and storage) in confined hog manure in 1997 was estimated to be in excess of crop needs at the farm level (Gollehon et al., 2001).

Most confined hog operations use either a slurry pit system or a liquid lagoon system for managing manure. Slurry systems store undiluted, untreated manure in watertight tanks or pits until it can be land applied. Storage can be either under the house or outdoors. The stored slurry is surface applied to fields by sprayer trucks or wagons, or incorporated into the soil with chisel plows behind nurse tanks, or directly injected into the soil with drag hoses. Most ammonia emissions from these systems are from the field where manure is applied (U.S. EPA, 2004).

Lagoon systems use open holding ponds to treat diluted manure for an extended period of time. Lagoons stabilize organic matter, reduce the nutrient mass that must be land applied, and vent a large quantity of the manure nitrogen as ammonia. Some of the diluted lagoon liquid is used to flush the production houses. The “digested” lagoon liquid is eventually sprayed on cropland. Lagoons are used primarily in warmer climates where the anaerobic processes can take place year round. Lagoon systems emit more ammonia per animal unit to the atmosphere than do slurry systems (U.S. EPA, 2004).

Because of the high cost of transporting manure relative to the value of the nutrients in the manure, farmers have an incentive to overapply manure to land located near their livestock facilities. The amount of manure generated on CAFOs and its estimated nutrient content indicate that 82 percent of hog CAFOs were overapplying manure nitrogen in 1998 (Ribaudo et al., 2003). Farmers can reduce threats to water quality by testing soil and manure for nutrient content, and applying nutrients at rates consistent with the agronomic needs of crops. Such an approach could force farmers to spread manure on more land, often requiring manure to be transported greater distances from the hog facility (Ribaudo et al., 2003). Farmers faced with nitrogen application restrictions through a required nutrient management plan—but not ammonia emission restrictions—might try to reduce the nitrogen content of manure as a means of reducing the amount of land needed for spreading, and limiting hauling costs. The nitrogen content of manure can be reduced by promoting the creation of ammonia and its volatilization to the atmosphere. This can be done by storing manure in uncovered lagoons and by surface applying slurry rather than injecting it (Sweeten et al., 2000). For example, the nitrogen available to crops in lagoon liquid is 70 percent lower when coming from an uncovered lagoon rather than a covered lagoon.

If, on the other hand, farmers face restrictions in ammonia emissions but not runoff, they can reduce emissions by adopting storage structures and management methods that reduce manure's contact with the air and maintain a low pH. Preventing the formation of ammonia preserves the nitrogen content of manure, increasing the availability of nitrogen for crops, as well as the risk of nitrogen loss to surrounding waters if the land base receiving lagoon liquid stays the same.

To examine the effect of potentially conflicting policies on a farmer's production decisions, we constructed a hog farm economic model. We evaluate three scenarios: (1) a nitrogen application standard as part of a nutrient management plan required by the 2003 CAFO regulations under the Clean Water Act, (2) a hypothetical ammonia emission standard based on available emission abatement technologies, and (3) a coordinated policy that meets both land application and ammonia emission standards. A positive mathematical programming model with calibrated cost functions captures the essential farm-level tradeoffs between air emissions and water discharges of nitrogen (see Appendix A—web only—for details). Farmers maximize profits given input prices, output prices (hogs and crops), regulatory requirements, and available cropland by choosing a manure management technology, the amount of land on which to spread manure, the acreage of each crop to plant, the amount of commercial fertilizer to purchase, and the number of hogs to produce. We assumed that the basic manure storage system (pit or slurry) would not change.

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 ammonia emissions or preserved in the manure storage and handling system 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. Water quality impacts are assumed to be directly related to the amount of nitrogen applied to cropland that is in excess of crop needs, after losses to the atmosphere. Air emissions are derived from total animal production and the type of storage/handling technology employed by the animal feeding operation.

The model is calibrated with data from the 1998 USDA-ARMS survey of hog operations, the most recent survey for hogs. In the analysis, eight representative CAFOs are depicted, corresponding to four major hog producing regions (East Corn Belt, West Corn Belt, Mid-Atlantic, and South and West) and two major manure storage technologies (lagoon and pit). We consider two technological options currently available to hog farms that influence the level of ammonia released to the air: the injection of manure into the soil and covering lagoons.

Single-Medium Environmental Policies

Baseline

Model results indicate how the two single-medium policies and a joint multimedia policy would alter farmers' decisions affecting production, input levels, nitrogen to soil and air, and the use of emission technologies relative to the baseline year 1998—the year of the survey to which the model is calibrated. Baseline costs and profits reflect production decisions made in the absence of any regulatory constraints. In the baseline year, all hog manure was applied onfarm to corn, soybean, and other crops at a rate 7.3 times greater than the nitrogen-based agronomic rate (table 3-1, column 1). This rate reflects the quantity of manure produced by farms relative to the amount of land on which manure was spread in 1998 and the crops reported as receiving manure. In the baseline year, about 10 times more ammonia nitrogen is released from manure storage facilities (lagoons and pits) than from fields. Total nitrogen released to the air in the form of ammonia (361,000 tons) 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. The high level of nitrogen released as ammonia implies that there is a significant potential for increasing manure nitrogen available for crops. We assume that both excess nitrogen and ammonia emissions in the baseline exceed environmental standards; i.e., further increases in either one would result in unacceptable degradations in environmental quality.

Wide geographical differences in application rates reflect the relative abundance of cropland on which manure is applied. Lagoon operations, located primarily in the Mid-Atlantic, apply manure nitrogen at 9.2 times the agronomic rate, on average, compared with 5.5 times the agronomic rate for pit operations, located primarily in the Corn Belt regions. Livestock operations in the Corn Belt tend to be more integrated with crop production than elsewhere,

Table 3-1

Production, profits, emissions, and technology adoption under nitrogen application standard (NAS), ammonia nitrogen standard (ANS), and both

Item	Base	NAS		ANS		NAS+ANS	
			% chg.		*% chg.*		*% chg.*
Hogs (*mil. cwt.*)	119.10	117.96	-0.96	118.26	-0.70	115.61	-2.93
Total profits (*mil. $*)	3,700	3,487	-5.77	3,426	-7.40	3,187	-13.87
Hog enterprise profits (*mil. $*)	3,047	2,837	-6.89	2,805	-7.93	2,568	-15.72
Ammonia N - storage (*1,000 tons*)	327.5	325.3	-0.68	203.3	-37.91	198.8	-39.29
Ammonia N - field (*1,000 tons*)	33.8	34.9	3.38	53.1	57.16	52.1	54.15
Ammonia N - total (*1,000 tons*)	361.3	360.2	-0.30	256.4	-29.02	250.9	-30.55
Excess N - soil (*1,000 tons*)	137.7	0.0	-100.00	246.4	78.95	0.0	-100.00
Application rate (*factor of agronomic rate*)	7.3	1.0	-86.38	17.6	140.37	1.0	-86.38
Manure transport costs (*mil. $*)	0.0	205.6	-	0.0	0.00	231.9	-
Manure N on-farm (*1,000 tons*)	183.6	51.8	-71.81	284.6	55.02	42.3	-76.96
Manure N off-farm (*1,000 tons*)	0.0	127.7	-	0.0	0.00	235.7	-
Cover lagoon (*% farms, all farms*)	0.00	0.00	0.00	36.42	-	36.42	-
Inject manure (*% land, all farms*)	25.56	22.55	-11.78	37.66	47.33	37.46	46.54

so they generally have more cropland available on the farm for spreading manure (McBride and Key, 2003). For pit operations, the amount of excess nitrogen applied to land that is not absorbed by crops is about the same amount of nitrogen released to the air as ammonia. Lagoon operations, in contrast, release far more nitrogen into the air, primarily from the lagoon itself.

Nitrogen Application Standard

The CAFO rules require farmers to follow a nutrient management plan that eliminates excess applications of nitrogen. In our first scenario, we assume each hog operator must meet a nitrogen application standard. Farmers adjust their operations to meet this standard at least cost. 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 shipments of manure off-farm to conform to this standard. As a result, total profits from the hog enterprise and the whole farm (accounting for crop production) decline about 6.9 percent and 5.8 percent (table 3-1, column 2).

Economic impacts are not distributed equally between the major manure handling technologies. Hog profits for farms using slurry systems decline 9.9 percent, versus 4.9 percent for farms using lagoon systems (table 3.2, column 2). Pit operations suffer larger losses because slurry manure contains more nitrogen than lagoon liquid. Even though pit farms tend to have more land available for spreading manure, the high nitrogen content of

Table 3-2

Production, profits, emissions, and technology adoption under nitrogen application standard (NAS), ammonia nitrogen standard (ANS), and both, by storage technology

Item	Base	NAS		ANS		NAS+ANS	
			% chg.		*% chg.*		*% chg.*
Lagoon operations							
Hogs (*mil. cwt.*)	70.76	70.52	-0.34	69.92	-1.18	68.50	-3.20
Total profits (*mil. $*)	2,019	1,929	-4.47	1,778	-11.95	1,686	-16.50
Hog enterprise profits (*mil. $*)	1,827	1,738	-4.88	1,586	-13.22	1,494	-18.26
Ammonia N - storage (*1,000 tons*)	255.0	254.1	-0.34	130.8	-48.69	128.2	-49.74
Ammonia N - field (*1,000 tons*)	14.8	14.7	-0.34	40.7	175.05	39.8	169.43
Ammonia N - total (*1,000 tons*)	269.8	268.8	-0.34	171.5	-36.43	168.0	-37.73
Excess N - soil (*1,000 tons*)	42.4	0.0	-100.00	136.3	221.64	0.0	-100.00
Application rate (*factor of agronomic rate*)	9.4	1.0	-89.31	25.4	171.11	1.0	-89.31
Cover lagoon (*% farms, lagoon farms*)	0.00	0.00	0.00	76.70	-	76.70	-
Pit operations							
Hogs (*mil. cwt.*)	48.34	47.44	-1.86	48.34	0.00	47.11	-2.54
Total profits (*mil. $*)	1,681	1,558	-7.33	1,648	-1.94	1,501	-10.71
Hog enterprise profits (*mil. $*)	1,220	1,099	-9.91	1,220	0.00	1,074	-11.91
Ammonia N - storage (*1,000 tons*)	72.5	71.2	-1.86	72.5	0.00	70.7	-2.54
Ammonia N - field (*1,000 tons*)	19.0	20.2	6.27	12.4	-34.54	12.3	-35.52
Ammonia N - total (*1,000 tons*)	91.5	91.4	-0.17	85.0	-7.17	82.9	-9.39
Excess N - soil (*1,000 tons*)	95.3	0.0	-100.00	110.2	15.53	0.0	-100.00
Application rate (*factor of agronomic rate*)	5.5	1.0	-81.88	10.7	93.27	1.0	-81.88
Inject manure (*% land, pit storage farms*)	48.67	42.93	-11.79	71.70	47.31	71.32	46.54

the slurry means they must still transport large amounts of manure off the farm, and incur high hauling costs.

The nitrogen application standard effectively eliminates excess nitrogen applied to the soil. The nutrient application standard also induces a 3.4-percent increase in the quantity of ammonia nitrogen emitted from fields (table 3-1, column 2), mainly because more land is receiving manure and because farmers that had been injecting slurry switch to surface application to use more manure and minimize off-farm transportation costs. However, the net effect of the policy on ammonia nitrogen emissions is very small, due mainly to the small decline in hog production. Hog production on each farm declines because of the increase in production costs relative to market prices for hogs (which are assumed constant). There is no real tradeoff between air quality and nitrogen available for crops because farmers were generally not taking steps to preserve the nutrient content of manure by preventing atmospheric losses in the first place. This suggests that large hog producers treat manure as a waste to be disposed of rather than a valuable source of nutrients.

Ammonia Nitrogen Limit

We also consider ammonia nitrogen limits based on the minimum levels obtainable employing currently available abatement technologies (lagoon covers and manure injection). For this policy simulation, manure nutrient application standards for protecting water quality are assumed not to exist. For pit operations, ammonia nitrogen emissions are constrained to 10 percent above the minimum obtainable if all manure is injected. For lagoon operations, ammonia emissions are constrained to 20 percent above what is obtainable if lagoons are covered. These limits were chosen so that costs to producers of meeting the emission standards are in the same range as under CAFO application standards and so that pit and lagoon operations face similar regulatory costs under the joint policy (next scenario). The constraint on ammonia emissions is in the form of a percentage reduction in net N emissions per pig.[1]

The ammonia nitrogen standard induces pit operations to switch from surface application to injection on some land, and induces some lagoon operations to cover their lagoons. The ammonia standard results in a 38-percent decline in ammonia emissions from manure storage facilities (the largest source of emissions) and a 57-percent increase in emission from fields, for a net decline in ammonia emissions of 29 percent (table 3-1, column 5). The increase in emissions from fields results because more lagoons are covered, which raises the nutrient content of the lagoon liquid applied to fields, resulting in greater nitrogen volatilization. The ammonia standard resulted in a 79-percent increase in excess nitrogen applied to soil—revealing an important tradeoff between water and air quality. For pit operations, the standard does not affect the profitability of the hog enterprise, so there is no hog production response (table 3-2). On the other hand, profits for operations with lagoons decline over 13 percent, resulting in a decline in production of about 1.2 percent, with no marketwide price effects accounted for.

[1]Another option would have been to place a direct restriction on the entire farm. This would provide a different incentive to the farmer than the per-unit output restriction, and would likely result in a different outcome (Helfand, 1991). How different is an empirical question, but the direction of change would be the same.

Additional Simulations

To explore the tradeoffs between water and air emissions in more detail, we perform two more simulations. First, we examine how the levels of excess soil nitrogen and ammonia nitrogen vary for different nitrogen application standards applied to CAFOs (fig. 3-1). The application standard is incrementally tightened from 50 percent greater than the agronomic rate to full implementation (where manure must be applied at the agronomic rate for all crops). Reducing the allowable nitrogen application rate (moving from right to left along the x-axis) results in a large decrease in the excess nitrogen applied to the soil, but almost no change in the amount of ammonia released. Farms were not conserving manure nutrients prior to the CAFO regulations, so the nitrogen application standards had little impact on air emissions. With no ammonia limits, tightening the nitrogen application standards to improve water quality produces only a minimal tradeoff in terms of lower air quality.

A much different outcome occurs if hypothetical restrictions are placed only on ammonia emissions and CAFOs do not have to meet nutrient application standards (fig. 3-2). A significant tradeoff between water and air quality would occur with increasing restrictions on ammonia emissions and no restrictions on nutrient application rates. Moving toward full implementation of emissions-reducing technologies (lagoon covers and manure injection) causes a large increase in excess soil nitrogen. Since there is no incentive to apply at agronomic rates, and spreading on more land would increase costs, manure nutrients are overapplied.

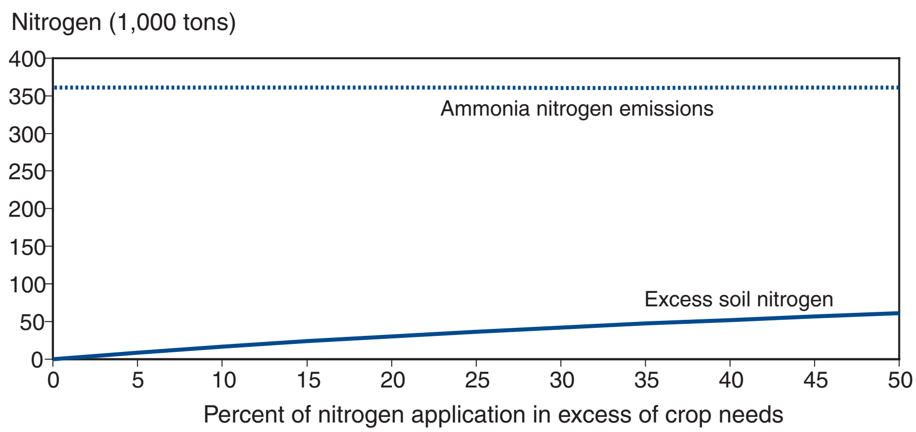
With no ammonia limits, tightening the nitrogen application standards to improve water quality produces only a minimal tradeoff in terms of lower air quality.

Coordinated (Air and Water) Environmental Policies

Relative to either of the single-medium policies, the joint policy is quite costly in terms of profits (column 7, tables 3-1 and 3-2). Hog operation and total farm profits decline by 15.7 percent and 13.9 percent relative to the base year. Production decreases about 3 percent. However, this policy

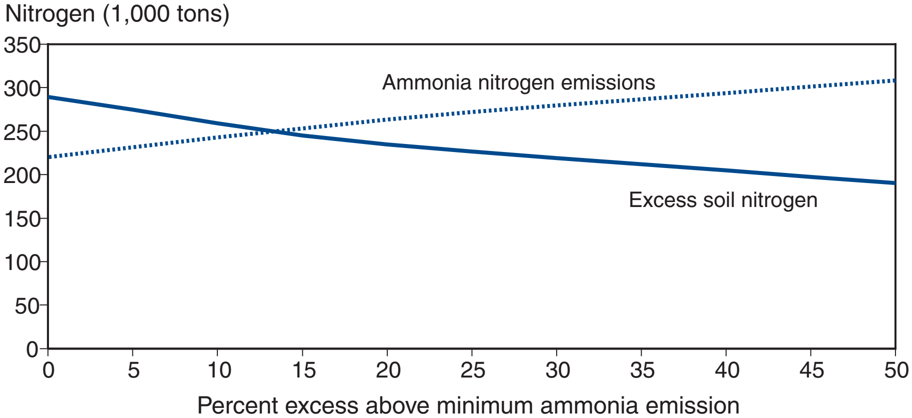
Figure 3-1

Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying soil nitrogen standards



Note: Ammonia emitted to the atmosphere measured in terms of nitrogen.

Figure 3-2
Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying ammonia nitrogen standards



Note: Minimum ammonia emission based on all operations adopting emissions-reducing management practices.

reduces ammonia nitrogen by about 30 percent relative to the levels under the CAFO regulations alone, and eliminates excess nutrient applications. Lagoon operations suffer the largest decline in profits, with hog profits declining 18.3 percent, compared with 11.9 percent for pit operations.

An indication that the individual policies could be in conflict is that the least-cost mix of technologies for addressing either an ammonia policy or a water policy is not the same as the mix of technologies that best meets a joint policy goal. Meeting the land application goal results in a decrease in the amount of manure that is injected, contrary to what would be required to meet the ammonia emission reduction goal. Similarly, meeting the ammonia reduction goal would result in a large increase in nitrogen applications that are in excess of crop needs.

This result implies that applying one policy after the other would result in higher costs than applying both simultaneously. To meet the ammonia emission goal after first implementing nitrogen application standards, manure injection on pit operations would have to increase 66 percent, rather than the 46 percent if the goals had been met simultaneously. This additional 20 percent of land requiring injection is the direct cost of implementing policies piecemeal rather than jointly. This land had been injected before the implementation of any policy, but shifted to surface application in response to the nutrient application regulations. To shift back to injection imposes a cost that would have been avoided if the policies had been implemented simultaneously. For lagoon operators, this conflict does not occur. Meeting the nutrient application standards first would not require any subsequent changes in storage technology to meet the coordinated policy goals (lagoons remain uncovered).

Farm-Level Decisions Have National Implications

This farm-level analysis highlights the economic and environmental tradeoffs that can occur with single-medium environmental policies as they are applied to hog farms. The two single-medium policies induce different responses. An ammonia emission standard alone would induce farmers to apply more excess nitrogen to the soil—a result likely to diminish water quality through increased nitrogen runoff and leaching. By itself, a nitrogen application standard to protect water quality does not have as dramatic an impact on ammonia emissions, but it does encourage an increase in surface application of manure, which increases potential ammonia losses from fields. Meeting both excess nitrogen and ammonia standards would be more costly than either single-medium policy.

Decisions made at the farm level are just the start of policy impacts. An operator who adopts waste management practices in response to regulatory requirements may also see an increase in production costs. Increased costs of production would, in turn, reduce the number of animals produced. When many hog farmers are affected by a policy change, new production levels may alter the market price of animal products and inputs (feedgrains, for example). Price changes springing from environmental regulations affect consumers and other sectors of the economy, and may cause animal producers to make further changes in their operations.