Animal Waste Regulation and Transboundary Water Quality

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Control of animal waste has been a major policy challenge. We identify the properties of efficient regulation and suggest that effective policies to control animal waste will enhance utilization of manure in local production and may change land allocation among crops. We also show that policies that aim to control local environmental problems, ignoring spillover among regions, may be significantly suboptimal and need to be replaced by policies with a global perspective.

The range and magnitude of impacts of animal waste are worldwide and vary among different regions. Animal waste is a key source of nitrates and salts impairing groundwater quality in California's San Joaquin Valley. Hypoxia in the northern Gulf of Mexico is linked to nitrogen and phosphorus loadings from the immense Mississippi River Basin. There, agriculture is by far the most important source of both nutrients, and manure is the biggest source of phosphorus and an important source of nitrogen. In the Chesapeake Bay, manure surpluses from the basin's animal husbandry accelerate eutrophication, which is harmful for commercial fisheries and recreational activities.

Over the past few decades, the number of animals per production facility has increased substantially and production has been concentrated geographically. As a result, local feed production cannot satisfy the nutritional needs of these growing production units. Feed is largely purchased from markets outside the production region, while the manure by-products from animals remain in the region. This leads to an accumulation of nutrients which, in turn, increases nutrient loading to ground and surface water systems. The challenge is to achieve profitable animal production while contaminating the environment as little as possible.

Any production tends to generate pollution as an unintended by-product. Without government intervention, no individual operator will factor the amount of pollution into decisions regarding the number of animals cared for on the land, manure-management technologies, crop choices, etc. Generally, it would be beneficial for society to pollute less than what is observed under a free market system. Yet, eliminating pollution altogether is too costly and regulation is needed to keep it at desirable levels that maximize societal welfare.

Regulation, on the other hand, is always defined for, and often differs among, given regions. In the United States, regulation of water quality is guided by the federal Clean Water Act (CWA). States emphasize designing, imposing, and enforcing the actual regulations imposed at the federal level. When regulating concentrated animal feeding operations (CAFO), for instance, states may establish rules that influence manure-application practices. As our economic analysis will demonstrate, regional regulation has serious caveats.

For this study, we create a stylized framework to illustrate regional regulation and its potential failure. Hereby, we establish a need for applied economic analysis to further clarify the problem and help improve existing policies. We examine the effects of regional (state level) regulation on the generation of residual nitrogen and phosphorus from animal and crop production.

We also show that stricter but uncoordinated environmental protection in one region may lead to increased environmental damage in the other. The two main reasons for this are: 1) Measures that reduce nutrient residuals, particularly crop choice, exhibit trade-offs between phosphorus and nitrogen residuals; and, 2) The role of nitrogen and phosphorus in generating externalities differs between regions.

Nitrogen and Phosphorus

Manure nutrients are useful in enhancing crop productivity, and can be utilized in production as fertilizers. The crucial difference between manure and chemical fertilizers is that a farmer is only able to choose the overall level of manure application, which determines the applied amounts of both nutrients. With chemical fertilizers, any combination of nitrogen and phosphorus are commercially available.

Nutrient requirements of crops vary significantly. Corn needs about 140 pounds of nitrogen and between 20 and 30 pounds of phosphorus per acre (at medium soil phosphorus values). Soybeans, on the other hand, can utilize atmospheric nitrogen and recommended phosphorus rates vary between 20 and 45 pounds per acre.

Also, the concentration of phosphorus and nitrogen in animal manure differ. Dairy manure contains about 1.5 times more nitrogen than phosphorus, while dry hog manure contains roughly equal amounts of both. To avoid the costs of applying both chemical fertilizers and manure,

Table 1. Decomposing the Decision-Making Process		
Decision Variable	**Economic Outcomes**	**Nutrient Residuals**
LIVESTOCK FARMER		
Number of Animals	Revenues from animal products Cost savings from utilizing manure; Production costs; Feed costs	Amount of manure increasing with the number of animals; N-P concentration in manure fixed for each production animal
Application of Manure on Own Land	Savings in chemical fertilizers; Hauling and application costs	Relatively scarce nutrient generates zero residual, positive residual for the other
Export of Manure to Crop Production Area	Revenues from selling manure; Hauling and application costs	Relatively scarce nutrient generates zero residual, positive residual for the other
Deposit Area for Excessive Manure	Free disposal on own land; Hauling costs if on crop farm	All applied manure excessive of crops needs adds to residual nutrients, regardless of location
Crop Choice	Savings in feed costs/revenues from selling; Fertilization costs	Crop specific N-P uptake
CROP FARMER		
Manure Import	Substitute chemical fertilizers	N-P of manure net of crop specific N-P uptake
Crop Choice	Revenues from selling; Fertilization costs	Relatively scarce nutrient generates zero residual, positive residual for the other

farmers choose the manure quantities on the basis of one nutrient, often nitrogen; while the other, often phosphorus, is applied excessively.

Residual nutrients, often coming in the form of runoff, are harmful for ground and surface waters. Protecting groundwater requires controlling nitrogen loading, and mitigating eutrophication requires reducing loading of either or both of the nutrients, depending on the watershed characteristics. Arid regions with little surface water, like California, tend to suffer from groundwater quality problems but face very little eutrophication. Agricultural regions draining into the Chesapeake Bay, on the other hand, may suffer from both problems. Regions located directly on the Bay may be more concerned with phosphorus than nitrogen, depending on the (perceived) effects nutrients have on eutrophication.

This discrepancy may cause one region to emphasize controlling nitrogen and another to control phosphorus. Problems can arise if regions share common surface waters, as one region may undertake measures that mitigate problems they experience but aggravate problems experienced by the other.

Two Farm–Two Region Model

We consider a stylized model of an upstream and a downstream region. The upstream agricultural region is comprised of a livestock farm and a crop farm. The downstream recreational region has no agricultural production but derives benefits from surface water quality. Nutrient residuals in the agricultural region are the only determinants of nutrient loading in both regions.

We assume that the agricultural region suffers from elevated nitrate concentrations in its groundwater and nitrogen-driven eutrophication in its rivers. Hence, its regulation focuses on nitrogen. The downstream recreational region is concerned with regulating phosphorus to protect its coastal waters.

The decision-making framework for total livestock and crop production relies on basic economic and technical characteristics. While it does not capture the complexities of economic decision-making or the nutrient loading governed by hydrology, it allows for sufficient details needed to obtain qualitative policy conclusions.

The objective in our model is profitability of the farms while accounting for the adverse effects of nutrient loading on the downstream region. We vary the way that profits and nutrient loading are weighed by assigning four alternative decision makers to conduct the optimization: the crop farmer, the livestock farmer, a regional policy maker, and a global (federal) policy maker.

The farmers' choices and the associated costs and benefits are presented in Table 1. The dark green color in Table 1 stands for revenues and the light green for costs associated with the choice variable given in the left column.

Manure nutrients used as substitutes for chemical fertilizers create economic value. The costs are created by hauling and application. The environmental damage is linked to residual nutrients, i.e., the differences in nutrients applied and nutrient uptake. The literature recognizes that under expected profit maximization of the farms, there will typically be some residuals generated.

Table 2. Numerical Example of Three Potential Outcomes								
Decision Maker	Number of Animals	Crop	Manure Generation (million gallons)	Application Livestock Farm (acres)	Application Crop Farm (acres)	Excessive Application (million gallons)	Nitrogen Residual (lb/acre)	Phosphorous Residual (lb/acre)
Crop and Livestock Farmers	1000	Double-crop soybean	3.94	800	0	1.81	72.5	97.7
Regional Policy Maker	990	Corn	3.90	800	91	0.0	0.0	103.0
Global Policy Maker	990	Double-crop soybean	3.90	800	450	0.58	14.8	40.0

We want to focus on characteristics of residuals when manure is the source of nutrients and policies differ regionally. Therefore, we assume chemical fertilizers create some residual nutrients, but we normalize this to zero. Furthermore, we assume that manure is applied at least according to crops' agronomic nitrogen needs but, due to the nutrient phosphorus ratio of manure, phosphorus is always applied excessively.

Given these guidelines, what do the choices of our decision makers look like? Table 2 considers three alternative situations representative of Midwestern farms. First, both livestock and field crop farmers interact, pursuing profitability without awareness of nutrient loading to ground and surface waters. This prompts policy makers to intervene. The regional policy maker considers only surface and groundwater quality problems in the agricultural region, while the global policy maker additionally considers the eutrophication of surface waters in the recreational region.

We assume a cow produces 12 gallons of fresh manure daily, and 126 pounds of plant-available nitrogen and 115 pounds of phosphate phosphorus annually. The crop choice is between corn and double-cropped soybeans after small-grain silage. The agronomic needs for corn and soybeans are 140 and 85 pounds of nitrogen and 25 and 52.5 pounds of phosphorus per acre, respectively (at optimal soil phosphorus value as per Maryland recommendations).

The first row in Table 2 presents the choices of the farmers who do not consider nutrient loading. Considering only profits, the livestock farmer ends up having 1000 animals (milking cows with an average weight of 900 pounds), which generate about four million gallons of fresh manure annually. The most profitable crop choice is the double-cropped soybean.

In this case, the farmer substitutes chemical fertilization with manure as long as the costs of hauling and application are below or at the costs of buying chemical fertilizers. Regarding this, the farmer ends up applying manure on all her farmland, but does not import anything.

The price received from the crop farm does not cover the costs of hauling and applying for farther distances. The excessive manure application is about two million pounds. The farmers' overall solution generates residual nitrogen of 72.5 pounds per acre and residual phosphorus of 97.7 pounds per acre.

Regional policy standards aim to eliminate nitrogen residues from the upstream region. At the livestock farm level, it leads to a switch to corn, a slight reduction in herd sizes, export of manure to the crop production farm, and reduced profits of the livestock farmer. Since corn consumes less phosphorous than soybeans, transition to corn increases the phosphorous residual. This happens despite the fact that the regional policy maker's solution utilizes the almost two million pounds of manure that were applied excessively.

The global policy maker (for example, state instead of counties) recognizes that rivers carry most of the dissolved phosphorus to the other region, and places more weight on phosphorus loading. She concurs with the regional policy maker's slight cut on animal numbers but maintains the farmers' initial choice of crops. She requires farmers to incur high costs from hauling manure to the crop production area, but allows some excessive application of manure. This creates about 15 pounds per acre of residual nitrogen and about 40 pounds of residual phosphorus per acre.

As a summary, the regional policy maker's intervention always improves surface and groundwater quality in the upstream region, but may simultaneously worsen surface water quality downstream. This follows from reductions in residual nitrogen but potential increases in residual phosphorus, which occur because the agricultural regional decision maker does not account for the phosphorous loading problem in downstream regions and simply focuses on the nitrogen loading problem of the agricultural region.

Discussion and Policy Implications

In the United States, nutrient management plans (NMP) are key to mitigating the impacts of excess nutrients from animal waste. Concentrated animal feeding operations (CAFO), i.e., large animal facilities, have to conduct and follow NMPs to balance the application and uptake of nutrients. NMPs follow either nitrogen or phosphorus standards and, in most cases, only apply to farmland controlled by the livestock facility.

In accordance with the Clean Water Act, each state has created a list of impaired waters and defined their critical pollutants. A phosphorus standard should be followed if *local* waters are designated phosphorus-critical and if there are significant risks for phosphorus loading. Otherwise, a nitrogen standard is often followed due to its lower compliance costs. If it is designated as critical for certain downstream waters to be free of phosphorous loading, a regional approach may aggravate downstream pollution. In our example, the regional policy maker's solution coincided with a nitrogen standard.

Our framework could be used to assess manure regulation in California. Here, two relevant pollutants for NMPs and environmental concern would be nitrates and other salts. Choosing techniques that allow nitrogen to evaporate in compliance with a nitrogen standard might aggravate problems of salt sequestration in soils and groundwater. If these techniques allow farmers to meet regulatory standards while applying more manure per acre, more salts per acre would be applied.

This paper raises further questions for economic and empirical analysis. Since NMPs are controlling the manure applications only on livestock farms, will tighter nutrient-use limitations as a result of residual effects induce unwanted and even illegal manure-handling practices? Dairy management plans in the San Jacinto watershed report manure as being both imported and exported from the region. They also suggest that illegal dumping is taking place. The challenge is not only to introduce regulation but also to enforce it; and the more costly the regulation, the more incentives there are for noncompliance.

Furthermore, there are suggestions that NMPs should be applied not only to livestock farms, but also to all farmland utilizing manure. This, too, might have unintended consequences. Crop farmers' willingness to accept manure as a substitute for chemical fertilizers depends, for instance, on his/her perceptions of its nutrient content. If these do not coincide with those set by NMPs, crop farmers' willingness to substitute manure would decrease. This would force the livestock farmers to either directly subsidize crop farmers' manure applications or to find manure application areas farther away. Both practices would increase livestock farms' compliance costs–and strengthen the desire for noncompliance.

Concentrated animal feeding operations (CAFO) have to conduct and follow nutrient management plans (NMPs), which are key to mitigating the impacts of excess nutrients from animal waste.

Finally, introducing policies based on a global perspective may be very beneficial to the United States or the state as a whole, but could have negative impacts in some of the affected regions. An example of this would be seen if the upstream region is forced to take uncompensated actions that improve the downstream region's water quality. This distributional conflict may lead to the use of political processes to prevent enactment of certain policies.

Lobbying by different regional groups could carry major implications for policy formation. Therefore, policy design may require incorporation of compensation mechanisms that will reduce the loss to upstream producers as they modify their actions to improve water quality downstream. The incorporation of political-economic considerations is becoming an important part of environmental policy design, and will have major effects on total societal welfare as well as the welfare of individual groups.

Suggested Citation:

Iho, A., D. Parker, and D. Zilberman. 2013. "Animal Waste Regulation and Transboundary Water Quality." *ARE Update* 16(3):8-11. University of California Giannini Foundation of Agricultural Economics.

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