PROPERTY RIGHTS AND THE ECONOMICS OF NON-POINT SOURCE WATER REGULATIONS IN AGRICULTURE:
A NEW BIOPHYSICAL-ECONOMIC METHODOLOGICAL APPROACH

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ABSTRACT

Several recent studies have examined how excess nutrient runoff from nitrogen and phosphorous have caused environmental damage in the United States. Perhaps the most significant is the hypoxia zone in the Gulf of Mexico. As a result, regulation of these nutrient levels has emerged as an important step toward environmental stewardship, yet this has been an uneven process. Some states have developed strict regulations to decrease nutrient runoff, but the majority of states have favored broader goals of reducing nutrient runoff using best management practices (BMPs) instead of strict regulations. Nevertheless, regulations that restrict the use of nutrients in production agriculture also restricts the property rights of input usability over said nutrients in the agricultural supply chain and its production processes, including at the farm-level.

This paper reviews the economic literature on non-point source water regulations to reduce nutrient runoff in agricultural production in the United States. A new methodological approach is outlined that uses the Agricultural Policy and Environmental eXtender (APEX) biophysical simulation model to understand alternative production practices and nutrient management strategy economics from a farm level perspective. Some empirical examples are presented to demonstrate the usefulness of this approach.

KEYWORDS: Water Quality, Water Regulations, Property Rights, Hypoxia Gulf of Mexico, Nutrient Management, Environmental Economics

INTRODUCTION

The agriculture industry has undergone significant changes in the past decade. Crop yields per acre have significantly increased in the past forty years (Matson et al. 1997). Farm size has shifted to the extremes with large and small farms becoming more prevalent leaving less mid-size farms over the past forty years (MacDonald et al. 2013). Increased crop yields and farm size distribution changes can be attributed to the intensification of management strategies on farms through changes in seed technologies, irrigation, pesticides, mechanization, and fertilizers (Matson et al. 1997; MacDonald et al. 2013). At the same time, we have observed a shift toward more vertically integrated operations in livestock production (e.g. poultry) and to a lesser degree in production agriculture. More vertically integrated operations have shifted the lion's share of property rights over input usage from agricultural producers to agribusiness firms through contracts.

Although modern agriculture has increased productive efficiency, such changes have caused some negative impacts on surrounding ecosystems (Coupe et al. 2012). For example, Coupe et al. (2012) have cited the degradation of water quality in the Mississippi Delta from human interaction and agriculture. Agricultural nutrients and sediment runoff from farms has been termed a non-point source (NPS) of pollution and has severely impacted the water quality in all types of waterbodies (Johansson and Kaplan 2004; Rabotyagov et al. 2010; Kling 2011; Bostian et al. 2015). The United States Environmental Protection Agency considers defines non-point source pollution as any [water] pollution that lacks a definitive source (502(14) of the Clean Water Act, year). Alternatively, point source pollution refers to a type of water pollution that has some discernible conveyance ("What is Nonpoint Source?" 2016).

Given the vast area containing numerous agricultural producers, the runoff of nitrogen, phosphorus, and sediment are considered non-point source pollutants. Nitrogen and phosphorus cause eutrophication of waterbodies across the United States. Eutrophication promotes algae growth and may result in a hypoxic (oxygen depleted) area (Rabotyagov et al. 2014; Ribaudo et al. 2016). Low areas of oxygen in water have significant impacts on the surrounding aquatic life. Large hypoxia zones now form seasonally around the globe. One in particular is of great interest to the U.S. because it occurs in the Gulf of Mexico where the Mississippi River converges into the ocean (Rabotyagov et al. 2014).

The key question is how to balance environmental stewardship with farm productivity and profitability throughout the United States. In the case of non-point pollution, the EPA has taken the policy perspective that some regulatory standards have been necessary to curtail harmful runoff of such nutrients as nitrogen and phosphorous in agricultural production. Under the directive of the Environmental Protection Agency (EPA), states have created new standards for water quality. These standards have been referred to as "numeric nutrient criteria" (NNC). The NNC establishes the amount of acceptable nutrient concentrations in a waterbody.

Current regulatory standards for water quality at the farm level do not exist evenly across the United States. Some states such as Florida have much more regulatory standard setting for water quality and how non-point source pollution sources should be managed. The more stringent the standard, the more restricting is the property right dimension of usability over nutrients in agricultural production practices. As a result, regulation in the form of standard setting creates limits on the usability of nutrients throughout the agricultural supply chain, including at the farm-level.

However, the Mississippi Department of Environmental Quality (MDEQ) has proposed a set of alternative NNC standards to the Mississippi Stakeholder community (citation). This has resulted in significant debate between the public, policy makers and the agricultural community. The question pertinent for the agricultural community is: How will various water quality standards affect the economics of farm level production costs? Are there ways of achieving both environmental protection while maintaining the productivity of agricultural lands? These are challenging questions for academics, especially due to the lack of adequate data.

In this paper, we summarize the current economic literature related to non-point source pollution management economics across the agricultural industry. The key contribution of this paper is to outline a new empirical methodological approach to evaluate the cost impacts of various production practices at the farm level using a biophysical simulation tool and enterprise budgets under various water quality standards. The approach proposed utilizes an economy of objective data.

BACKGROUND OF LITERATURE

Access to water and water quality standards has been a major focus in American agriculture. As such, the issue of setting water quality standards and their associated benefits and costs has received much attention in the environmental economics literature. For instance, Kling (2011) concluded that 22 percent of the impaired river miles in the U.S. come from agricultural pollution and that agriculture is now the single highest source of that impairment. The Mississippi Department of Environmental Quality (MDEQ) has stated that 45 percent of Mississippi's rivers and streams are considered to be impaired (MDEQ 2014). With concerns over water quality and further damages to the Gulf of Mexico, the economic examination of alternative water regulations has taken center stage. Biophysical models, math programming, and other optimization techniques have been used to evaluate different ways of reducing nutrient pollution (Randhir and Lee 2000; Paudel et al. 2003; Harman et al. 2004; Osei et al. 2008; Rabotyagov et al. 2010; Kling 2011; Bostian et al. 2015).

This paper uses the term "biophysical models" to describe three models in particular: the Environmental Policy Integrated Climate (EPIC), the Agricultural Policy/Environmental eXtender (APEX), and the Soil and Water Assessment Tool (SWAT). These models are capable of calculating sediment loading, nutrient transport, and crop yields, but differ on complexity and scale of use (White et al. 2014). The biophysical models will be further explained in the methods and materials section of this paper.

Literature associated with water quality regulations can also be divided by the scale of the study. A sizable portion of economic examinations of alternative water quality standards are performed on a large scale (watershed/regional), while some are performed on a smaller level (field/farm). However, not many studies have been performed at the farm level using biophysical models. For the purposes of this paper literature related to examining the effects of alternative water quality standards will be divided into three categories: 1) biophysical models were not used to evaluate alternative water quality standards, 2) biophysical models were used on a large scale (large watersheds/regional) to evaluate water quality policies, and 3) biophysical models used to evaluate different standards at the farm level.

No Biophysical Models

Many studies have been conducted to assess the effects of water quality standards or regulations on the surrounding environment and the economic impacts of abiding by such standards or regulations without the use of biophysical models (Posnikoff and Knapp 1997; Johansson and Kaplan 2004; Rabotyagov et al. 2010; Kling 2011; Bostian et al. 2015). There are many alternative regulatory policies to reduce nutrient pollution from agriculture and there are different forms of agricultural pollution; deep percolation issues and non-point source pollution, to name a few. This study is focused on the issues of non-point source pollution. However, studies have been performed to understand control costs of deep percolation (Posnikoff and Knapp 1997). Posnikoff and Knapp (1997) investigated control costs of deep percolation in California using a static optimization model, varying crop mix, irrigation technologies, and amount of water applied. Posnikoff and Knapp (1997) found that deep percolation levels are reduced through increased environmental and disposal costs. Johansson and Kaplan (2004) reviewed the punishment or reward approach the US government employed to help livestock and crop producers abide by federal water quality standards. Livestock and other protein producers were punished for excess disposal of animal waste and crop producers were able to purchase subsidized animal manure to apply to the crop fields. Johansson and Kaplan (2004) found that this approach results in a decrease in livestock production and an increase in crop production along with increased livestock and other protein prices.

Rabotyagov et al. (2010) and Kling (2011) both discuss the relation of nutrient runoff from agriculture to the overall degradation of waterbodies across the US and the Gulf of Mexico. Rabotyagov et al. (2010) researched the least-cost estimates for controlling agricultural related nutrient contributions to the Gulf of Mexico in a large scale study on the upper Mississippi River Basin. Kling (2011) re-stated some previous ideas on how best to overcome issues of non-point source pollution from agriculture. A case study was then performed on a watershed in Iowa under a tradable point abatement system to understand the total cost to the watershed of abiding by the nutrient reductions. Bostian et al. (2015) utilized an economic integrated-biophysical hybrid genetic algorithm to assess the tradeoffs of water quality for agricultural production on both the watershed and farm level in Oregon by producing an optimal tradeoff frontier. Significant variation in tradeoff values were found across the basin as well as increased production costs. Each of these studies found stricter water quality regulations/standards have increased costs on the surrounding areas and producers.

Biophysical Models used for Regional or Watershed Analysis

One of the first biophysical models, EPIC, was developed as a field level tool to estimate soil productivity in response to the Soil and Water Resources Conservation Act analysis for 1981 (Gassman et al. 2004). The EPIC model received many updates and upgrades over time and eventually a successor, the APEX model. The APEX model was developed in the 1990's to address livestock and other agriculture systems on a small watershed or farm basis (Gassman et al. 2004). EPIC and APEX have been widely used across disciplines to simulate nutrient transport and farm activity. This second stream of literature is associated with studies that have been performed using the EPIC, APEX, or SWAT models.

Bernardo et al. (1993) used a three-stage modeling framework that consisted of the EPIC model, a math programming model, and an aquifer hydrology model (MODFLOW) to evaluate the economic and environmental effects of possible regulatory policies on agricultural groundwater in the Central High Plains. Different policy alternatives of reductions in fertilizers and pesticides were tested and it was concluded that for the best-case policy alternative, regional profits would decrease by 20%. Mapp et al. (1994) continued the work of Bernardo et al. (1993)

using the same three-stage framework, but adding an additional restrictive scenario on producers. Similar results were found to Bernardo et al. (1993).

Nitrogen and phosphorus are not the only pollutants agriculture contributes to US waterbodies. Qiu and Prato (1999) utilized the Soil and Water Assessment Tool (SWAT) along with a math programming model to maximize the net return of a watershed under three different atrazine abatement policies. It was concluded that spatial characteristics of the watershed significantly impact the cost-effectiveness of different abatement policies and that it may be possible to tailor abatement policies to specific farms in a watershed, but this may be considered an infringement on producers' rights. Paudel et al. (2003) researched the economic and environmental impacts of alternative water quality standards on a watershed in Louisiana and a watershed in Mississippi. The study was concerned with optimal litter application rates using APEX to create data for the Mississippi watershed. Paudel et al. (2003) concluded that stricter environmental regulations led to lower total profits and litter use in the area. This is a common conclusion in these studies.

Biophysical Models on a Farm Level

The third and final stream of literature discussed in this paper are articles and studies using biophysical models on a farm or field level. Chowdhury and Lacewell (1996) used EPIC to understand the cost-effectiveness of environmental policies on groundwater contamination in the Seymour aquifer in Texas. Data from a simulated representative farm was used in an optimization model to find the profit maximizing farm plan under different environmental policies.

Randhir and Lee (1997) and Randhir and Lee (2000) studied the farm-level response to water quality constraints using a nonlinear math programming model and the EPIC model. The level of standard, pollutant standard, and policy instrument in place to enforce the standard all had an effect on farm income, risk, and NPS pollution. Osei et al. (2008) created representative farms for sub regions in Texas in the APEX model. A combination of the APEX model and a farm economic optimization model were used to understand impacts on water quality and profits for animal feeding operations under different manure application rates to adhere to the agro environmental policies. The results from the baseline operation were compared to the alternative manure application rate scenarios. Although Osei et al. (2008) was intended as a large scale study, it shows that APEX can be used to create data in different locations to understand impacts of environmental quality standards. Randhir and Lee (1997), Randhir and Lee (2000), Chowdhury and Lacewell (1996), and Osei et al. (2008) all found lower (implied or explicitly stated) producer profits under the different environmental quality standards.

APEX and other biophysical models have been used to simulate different practices on large scales and at the farm level. Earlier it was shown APEX was used to simulate different manure application rates on animal feeding operations in Texas in Osei et al. (2008). Bernardo et al. (1993) and Mapp et al. (1994) utilized the predecessor to APEX, EPIC, to understand the effects of different fertilizer restrictions on groundwater quality. Chowdhury and Lacewell (1996) used EPIC to estimate environmental policies effects on groundwater. Paudel et al. (2003) used APEX to create data for analysis on different manure application rates in Mississippi on the watershed scale. These articles show the applicability of the biophysical models. However, using the APEX model for analysis of regulatory implications on water quality and runoff has not yet been established as a method to understand profitability and reductions in agricultural pollution under different alternative production practices at the farm level. It is exactly this empirical approach this paper proposes, to better understand the possible ramifications of water quality standards in the Mississippi Delta at the farm level.

A NEW METHODOLOGICAL APPROACH

The new methodological approach proposed to empirically analyze the effects of the alternative numeric nutrient criteria requires the use of the biophysical model APEX. APEX is the advancement of the EPIC model. The EPIC model is a homogeneous single field scale model. The evolution of EPIC into APEX was needed to simulate multiple fields, farms or small watersheds, and gain information on total runoff values for the entire simulated area of land. APEX was introduced to understand how management affects environmental and production issues at the farm or small watershed level (White et al. 2014). APEX has the capability of simulating many different conservation practices in row-crop agriculture or in other agricultural sectors such as animal feeding operations. APEX runs on a daily time step with crop growth being calculated by heating units from historical weather data. More information on the APEX and EPIC models can be found in Gassman et al. (2004). This paper will not discuss the SWAT model because it is not relevant to the research itself.

This study utilizes the Mississippi Delta as a case study. Proposed numeric nutrient criteria by the Mississippi Department of Environmental Quality (MDEQ) may affect the way Mississippi producers in the Delta manage production. The abilities and acceptance of APEX are widely known to many disciplines, especially the agricultural engineering discipline and many plant and soil science disciplines. However, agricultural economics has not shown the interest in

APEX that other disciplines have. The proposed approach to evaluating possible water quality standards relies heavily upon the ability of APEX itself and the APEX user.

We propose to use APEX to create a representative farm in the Mississippi Delta subject to county specific natural characteristics. This farm is characterized by the soil type(s), different fields, restriction to corn and soybean rotation, weather, and furrow irrigation. The farm, once created, will be simulated under "current" production practices for the Mississippi Delta. This "current" farm will then be adjusted in its management practices for alternate scenarios. The scenarios are changes in the production behavior to not only produce the crop, but in effort to reduce agricultural non-point source pollution. Table 1 lists and describes these scenarios. Rabotyagov et al. (2013) used alternative production practices to understand profitability on the farm. The alternative production practice scenarios from Rabotyagov et al. (2013) are used the alternative production practices used in this study. Not all scenarios from Rabotyagov et al. (2013) were used.

Table 1 Description of Alternative Production Scenarios

	Conservation Practice	Description
1	Baseline	Today's current practices in MS Delta
2	No till	No till as specified in APEX
3	Fertilizer Restriction	Reduce nitrogen applications by 20%
4	Cover Crops	Use cover crops between crop rotation
5	No Till and Fertilizer Restriction	No till and reduction in nitrogen fertilizer applications by 20%
6	No Till and Cover Crops	No till and cover crops between crop rotations
7	Fertilizer Restriction and Cover Crop	Reduce nitrogen applications by 20% and use cover crops
8	No Till and Fertilizer Restriction and Cover Crop	No till and 20% reduction in nitrogen applications and cover crops

The farm will be simulated under each of the different alternative production practice scenarios for 40 years. The period that simulation will occur will be from 1970 to 2010 using daily historical weather data. Daily precipitation, temperature, and solar radiation are inputs in the APEX model. Other data will be discussed later in the paper. Enterprise budgets will be constructed, if not already available from Mississippi State University Extension Service, to compare profits across the different production scenarios. The APEX model will produce data on yearly crop yields and runoff amounts of total nitrogen and total phosphorus. Once simulations have run and APEX has been yield calibrated, the percent changes in total nitrogen (TN) and total phosphorus (TP) will be calculated from the baseline to the alternative scenarios. The baseline scenario profit and runoff statistics will then be compared to the alternative production scenarios. Comparisons will also be made between the alternative production scenarios.

Although the proposed NNC standards for Mississippi have not been legally enacted, and it is not exactly clear as to how these may affect producers, it is wise to consider different acceptable thresholds of nutrient concentrations in runoff from fields. Hypothetical thresholds (level of nutrient concentrations in water) will be used to evaluate the different production practices possibly employed by the producers. The thresholds are useful so for comparing production practices under different regulatory standards. The thresholds may also show that under different standards, different production practices may be more profitable than others.

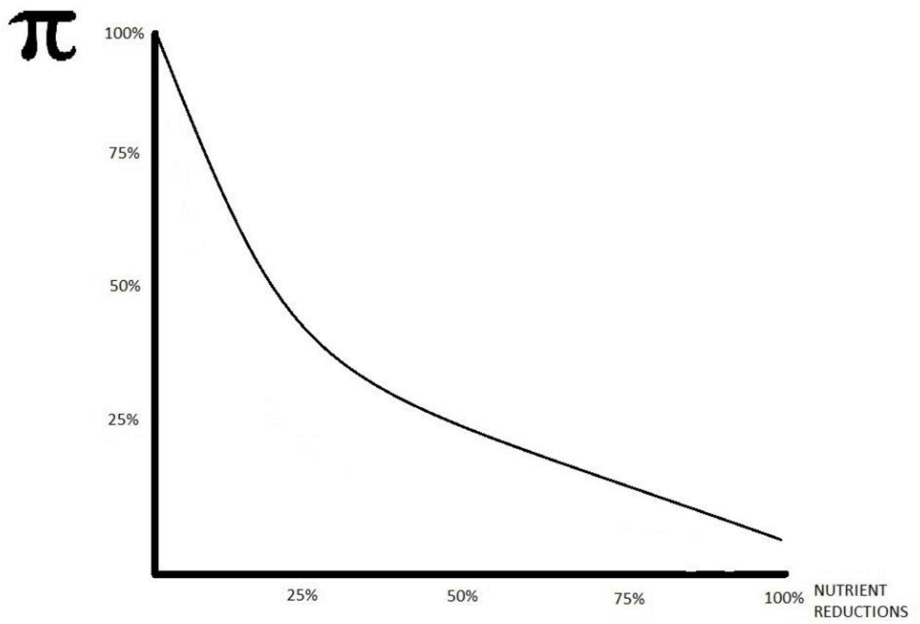
APEX communicates with a database that is specific to a state, in this case Mississippi. The database contains information on production practices, soil types, weather stations, runoff values, crop information, etc. This data was collected through the Conservation Effects Assessment Project (CEAP) which is a multi-agency effort to better understand the effects of conservation practices on surrounding ecosystems. The data collection was under the directives of the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The CEAP data has historical daily weather values that include temperature, radiation, precipitation, etc. This weather data is used in the APEX model not only for the daily time step crop growth, but also for the nutrient and water runoff.

Example Empirical Results

Figure 1 shows an example of the type of expected empirical results from the proposed approach and is a depiction of possible profits at different levels of nutrient reductions. This applies to nitrogen and phosphorus independently or combined. The horizontal axis is percent nutrient reductions from a baseline set of production practices from an example farm operation. The vertical axis shows profit levels as a percentage of "maximum profit" (assumed to be profit from baseline production). The nutrient reductions are differing levels of nutrient standards set by the effects of the NNC standards. The actual profit line is made up by connected points of profit related to the nutrient reductions. The points on the profit line are the "maximum profit" attainable from the alternative production scenarios so that the producers can evaluate the tradeoff between profits per nutrient reductions, other things equal.

The profit points may or may not be the maximum profit because of the limited set of production practices available and the restriction on baseline farm crop mix. However, holding crop mix constant and only using the alternative production practices as stated in Table 1, the profits will be the best-case or most-profitable under each restricted set of nutrient thresholds. The curvature of this profits-nutrient reduction tradeoff curve is unknown. Only through the new methodological approach that we have outlined can empirical estimates be generated. Empirical estimates for measuring tradeoffs between profits and nutrient reduction goals creates a type of elasticity that policy makers and the agricultural community would be interested in learning.

Figure 1. Example Empirical Results



LIMITATIONS AND IMPLICATIONS

The proposed methodological approach to evaluating numeric nutrient criteria relies heavily upon the ability of the APEX model itself. The APEX model is widely used in many disciplines. The predictive capabilities of the model are based on theoretical algorithms from many different disciplines including hydrology, plant sciences, and others. More information on the theoretical background of the APEX model can be found in Williams and Izaurralde (2006).

One of the strengths of this approach is the ability to predict crop yields under different management strategies and produce runoff and nutrient transport information. The APEX model can be thought of as a joint product model where nutrient runoff and crop yields are produced together. Crop yield predictions alone are impressive and speaks to the overall capabilities of the model. This approach allows researchers the capability to simulate many years and obtain data in a very short period of time, whereas real data would take years to complete and compile. Using the APEX model greatly shortens the length of time and offers great flexibility to the researcher. Another strength of this approach is the fact this is a farm level analysis and has the ability to help producers better understand different production practices and the effect on surrounding ecosystems.

CONCLUDING REMARKS

In this paper, we propose a new method for evaluating the economics of water quality standards on farm level agricultural production. The proposed method involves using the biophysical simulation tool APEX to simulate a farm under different production practices, holding crop mix constant, then assessing the profitability of these management strategies under different water quality standards. This new approach can guide legislators and other government agencies as to how best approach new agricultural/environmental regulations or standards. However, this approach should not be considered as a final answer to whether or not to implement a regulatory standard, but rather an integrated approach to examine both the costs and benefits associated with potential water quality standards. To that point, we proposed to use the APEX model to model farm level operations and connect those outputs (e.g. yields, runoff) to budgets for alternative agricultural production units to assess benefits and costs of various standards.

Connecting APEX to the costs and benefits of alternative production practices in place-specific agricultural production areas opens up the possibility to examine how macro water quality standards may affect farm-level agricultural production practices to be used and the associated value from each approach. That type of information is exactly what regulators and the agricultural community need to know to make informed decisions regarding water quality standard setting in the global agricultural production environment.

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