Environmental Risk Assessment under Environmental Standard and Safety-First Constraints

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Abstract

The uncertainty weather condition could pose some challenge in achieving environmental target. In this study, we use a bioeconomic model to calculate the impacts of alternative management systems. Under different safety-first constraints on the levels of environmental runoff, obtaining from APEX, optimal net return of alternative cropping practices is estimated.

I. Background

A concern of adverse environmental impacts in association with agricultural practices in the United States has been steadily increasing. A number of government programs to lessen such problems have been introduced, including Total Maximum Daily Load environmental standards (TMDLs), which soon will be effective. TMDLs are under consideration to reduce environmental runoff of nutrients, chemicals and sediment. Best management practices, including crop rotations and alternative tillage practices (no-till and conservation tillage), may help farmers comply with TMDL standards, while minimizing losses in farm profits. However, due to the uncertainty of agricultural nonpoint pollution, which depends on a number of factors, such as weather, environmental standards may be achieved only at a certain level. The uncertainty weather condition could pose some challenge in achieving environmental target. Since achieving environmental standard is unlikely, safety-first plays significant role in environmental policies.

To estimate the environmental and economic impacts of various cropping practices while taking into account the stochastic nature of environmental amenities, a number of risk models have been applied including chance-constrained, Target MOTAD, and Upper Partial Moment (UPM). To apply chance-constrained, a specific functional form of the environmental variables is required, which could pose some limitation to the model. Environmental variables could vary from site to site due to weather and other physical conditions. This specified of functional form of environmental variables has significant impact on choices of agricultural practices. For Target MOTAD, instead of specifying the distribution functional form, it treats the sample of variables as an empirical distribution, and the results of the optimization are valid as long as the empirical distribution represents the true distribution. However, the environmental risk level is chosen exogenously, which pose skepticism to the model. For this study, an upper partial moment (UPM) is applied. Unlike Target MOTAD, the environmental risk level is endogenously determined after the desired compliance probability with the objective is specified. To obtain environmental runoff, Agricultural Policy Environmental Extender, or APEX (Blackland Research Center, 1999; Williams et al., 2000) has been used to estimate nitrate runoff and sediment from various cropping practices of Deep Hollow watershed, Mississippi. We use a bioeconomic small watershed model to calculate the impacts of alternative management systems. The model merges physical data and biological data to analyze various management decisions and to simultaneously determine optimal management in terms of profit and environmental quality. Under different safety-first constraints on the levels of environmental runoff, obtaining from APEX, optimal net return of alternative cropping practices is estimated.

II. Analytical Approach

Our analytical approach is a two-part process. In the first stage of analysis, we develop the biophysical model in which we use APEX to estimate environmental runoff and yields under a number of scenarios. The outputs of interest from this model are expected crop yields and expected runoff of nitrogen and sediment. In addition we have developed scenarios in which filter strip practices are examined. In the second stage of analysis the optimal net return under safety-first constraint is calculated using the Generalized Algebraic Modeling System (GAMS) along with information on yields, crop prices, production costs and environmental parameters derived from APEX. Optimality of the system is determined by maximizing net returns across the entire watershed.

Watershed Level Physical Model

Site information such as cropping practices, soil types, topography and meteorological data has been collected over a number of years in the project, but in this paper, we focus on the year 1999 as the basis for our analyses. Traditional farm models assume that a farmer's production decisions are constrained by various factors such as amount of land, labor and other available inputs. An extension of the traditional model that we use in our analysis is a bioeconomic model. Our model is developed for the Deep Hollow watershed, and we extrapolate the model results over a 25-year time period. The underlying physical simulation model incorporates nearby weather conditions in the watershed, nutrient uptake and the timing of planting and harvesting of crops.

The bioeconomic model uses the Agricultural Policy Environmental Extender, or APEX (Blackland Research Center, 1999; Williams et al., 2000), which was developed as an extension of the EPIC (Erosion-Productivity Impact Calculator) model to small watershed level by the US Department of Agriculture's Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) in the early 1980's (Sharply and Williams 1990 (a and b)). APEX is designed to simulate biophysical processes and the interaction of cropping systems with management practices, soils and climates over long time periods. APEX captures timing of planting and harvesting and the use of cultural BMPs, and produces environmental parameters where water flows through small watersheds as surface, channelized and subsurface flow. APEX has flexibility in allowing for model calibration with existing data. In this study, we are interested in calibration of our model to correspond with onsite empirical measures of environmental parameters.

The watershed level model uses data inputs that replicate physical, meteorological and agricultural characteristics of the Deep Hollow Watershed. The watershed consists of 10 fields in which the primary crops grown have been cotton and soybeans. Within the watershed, there are 6 different soil types: Alligator, Arents, Arkabutla, Dubbs, Dundee and Tensas. In each field is a combination consisting of 2 to 3 soil types resulting in 22 subfields of unique soils (Table 1).

Approximately 20 inputs into the APEX model are needed for each subfield in order to perform simulations from which to obtain expected yields and nutrient and sediment runoff. The inputs include weather, soil type, soil erodibility factors, topography (as measured by average slope length and steepness), distance from fields to watercourses, relative geographic location of fields within the watershed, crop rotation, tillage practices and fertilizer and chemical use. As part of the MDMSEA project, the soils and topography of these fields have been measured to a high degree of accuracy.

The crops considered are continuous cotton and continuous soybeans under conventional tillage. We generated these outputs from the APEX model in order to use them as inputs to the economic optimization model described in the next section.

In our study, we will also calibrate our model to correspond with onsite empirical measures of environmental parameters. Uncertainty environmental impacts due to stochastic weather conditions will be simulated using APEX. Historical data of precipitation, collected from a nearby weather station (Greenwood Lefore Art), are divided up to a number of intervals, which correspond to the state of nature. The probabilities will be determined by dividing the number of observations in each interval by the total number of years.

Optimization with Safety-first Constraint

The optimal net returns of total watershed under safety-first constraints are estimated. The safety-first concept is applied to investigate economic decision under environmental uncertainty. Under safety-first rules, the decision maker concern with the probability of environmental variables falling below target values. The UPM model to evaluate environmental risk applied by Qui et al. (2001) can be written as

Maximize $E(z) = \sum_{j=1}^{n} c_j x_j$

Subject to $\sum_{j=1}^{n} a_{kj} x_j \leq b_k \quad k = 1,....,K$

$$t - \sum_{j=1}^{n} n_{rj} x_j + d_r \geq 0 \quad r = 1,....,s$$

$$\sum_{r=1}^{s} p_r d_r - q(t) = 0$$

$$t + L^* q(t) \leq G_e$$

for all x_j and d_r greater than zero, where t is an endogenously determined reference level for the environmental variable, d_r is zero or deviation above t for state r, and $q_t = q(1,t)$

In our study, nutrient and sediment runoff are simulated using, which is then used in a mathematical optimization program using GAMS. Therefore, an economic optimization model and assess environmental risk of reduced nutrient and sediment runoff by incorporating the safety-first model constraints.

III. Preliminary Results and Conclusions

Regarding uncertainty of environmental impacts (sediment and nitrate runoff) of cropping practices due to stochastic weather condition are simulated under 15 states of nature, using APEX. Information on variable costs is obtained from on site data. To calculate net returns, five years (1995-1999) average market prices of cotton and soybean in Mississippi are used.

For the baseline scenario, total watershed net returns along with amount of sediment and nitrate runoff are calculated. The optimal net returns of the whole watershed subject to land constraint are estimated, using mathematical program, GAMS. The environmental goals are to reduce sediment and nitrate runoff by 25% and 50% from the baseline levels (0% reduction in pollutants). Under UPM model, probability of achieving such goal as well as environmental goals is incorporated to safety-first constraint. In this study, probabilities of compliance with environmental goals are set to 0.50, 0.75, 0.85, and 0.95. Even under the baseline scenario of 0% reduction in sediment and nitrate runoff, there are 4 possible compliance probabilities of 0.50, 0.75, 0.85, and 0.95. The environmental constraint becomes more restrictive as the reduction level and the probability of compliance increase. GAMS are used to solve the optimal net returns under the UPM environmental safety-first constraint.

For the baseline scenario, under conventional tillage practice, the net returns, sediment and nitrate runoff are $16,535, 12.6 tons, and 44 lbs, respectively. The environmental goal are 12.60, 9.45, and 6.30 tons for sediment and 44.40, 33.30, and 22.20 pounds for nitrate runoff, which correspond to a 0%, 25%, and 50% reduction in the baseline environmental reduction levels (Table 2 and 3).

Target value (t) of sediment and nitrate runoff, and sediment and nitrate risk levels $q(t)$ are also reported in Table 2 and 3. As the compliance probability to the sediment and nitrate runoff goals becomes higher the expected deviation $q(t)$ above the reference t value becomes smaller. In other words, a less deviation from reference value is allowed when the compliance probability is higher. For instance, the expected deviation falls from 1.31 tons to 0.03 tons as compliance probability for achieving 25% sediment reduction increases from 0.50 to 0.95, which implies a reduction in the sediment risk level (Table 2). In this exercise, only conventional tillage practice is considered. For further study, conservation and no tillage practices will be included, which the optimal land allocation among the various tillage practices will be estimated.

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Table 1: Composition of Subfields in Deep Hollow Watershed, MS

Field ID	*Acres*	*Soil*	***% Soil***
XP3A	24.8	Dubbs	7.75
XP3A		Tensas	3.11
XP3B	12.0	Dubbs	2.25
XP3B		Tensas	1.55
XP3B		Dundee	1.04
XP3C	12.4	Dubbs	0.66
XP3C		Dundee	1.04
XP10	37.1	Tensas	6.99
XP10		Dundee	8.30
XP10		Dubbs	1.80
XP1	17.2	Arkabutla	12.27
XP2W	29.5	Tensas	14.09
XP2W		Alligator	3.18
XP2W		Arkabutla	1.24
XP2E	29.5	Tensas	14.50
XP2E		Alligator	3.28
XP2E		Arkabutla	1.24
XP8	9.0	Alligator	2.36
XP9A	12.6	Arkabutla	6.04
XP9A		Arents	2.10
XP9B	10.6	Arents	1.57
XP9B		Arkabutla	3.64

Table 2. Upper Partial Moment Model for Sediment Reduction

Prob. β	Sed. Goal (tons)	Net Returns $	t (tons)	$\theta(t)$ (tons)
0.50	12.6	16,275	9.31	1.65
	9.45	15,744	6.82	1.31
	6.3	15,212	4.33	0.99
0.75	12.6	15,930	10.46	0.54
	9.45	15,467	7.8	0.41
	6.3	15,004	5.13	0.29
0.85	12.6	15,771	10.86	0.26
	9.45	15,347	8.12	0.2
	6.3	14,919	5.36	0.14
0.95	12.6	15,533	12.56	0
	9.45	15,170	9.16	0.01
	6.3	13,407	5.79	0.03

Table 3. Upper Partial Moment Model for Nitrate Reduction

Prob. β	Nitr Goal (lbs)	Net Return $	t (lbs)	$\theta(t)$ (lbs)
0.5	44.4	15,987	30.51	6.94
	33.3	15,482	21.06	6.12
	22.2	14,296	13.84	4.18
0.75	44.4	15,546	31.62	3.19
	33.3	14,769	26.11	1.8
	22.2	12,623	16.99	1.3
0.85	44.4	15,414	36.21	1.23
	33.3	14,487	26.98	0.95
	22.2	12,003	17.92	0.64
0.95	44.4	14,773	42.16	0.11
	33.3	13,373	32.15	0.06
	22.2	10,631	21.66	0.03