Assessing the Costs and Environmental Consequences of Agricultural Land Use Changes: A Site-Specific, Policy-Scale Modeling Approach

JunJie Wu, Richard M. Adams, Catherine L. Kling, and Katsuya Tanaka

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Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu

JunJie Wu is an associate professor, Richard Adams is a professor, and Katsuya Tanaka is a graduate student, all in the Department of Agricultural and Resource Economics at Oregon State University. Catherine Kling is a professor of economics and head of the Resource and Environmental Policy Division in the Center for Agricultural and Rural Development at Iowa State University.

For questions or comments about the contents of this paper, please contact JunJie Wu, 200A Ballard Extension Hall, Oregon State University, Corvallis, OR 97331; Ph: 541-737-3060; Fax: 541-737-2563; E-mail: junjie.wu@orst.edu.

Abstract

The growth in federal conservation programs has created a need for policy modeling frameworks capable of measuring micro-level behavioral responses and macro-level landscape changes. This paper presents an empirical model that predicts crop choices, crop rotations, and conservation tillage adoption as a function of conservation payment levels, profits, and other variables at more than 42,000 agricultural sites of the National Resource Inventory (NRI) in the Upper Mississippi River Basin. Predicted changes in crop choices and tillage practices are then fed into site-specific environmental production functions to determine changes in nitrate runoff and leaching and in water and wind erosion at each NRI site. This policy-scale model is applied to the case of green payments for the adoption of conservation practices (conservation tillage and crop rotations) in the Upper Mississippi River Basin, a region under scrutiny as a significant source of nutrient loadings to the Mississippi River, causing hypoxia in the Gulf of Mexico. Results from this application suggest that payments for conservation tillage and crop rotations increase the use of these conservation practices. However, the acreage response is inelastic and the programs are not likely to be cost effective on their own for addressing the hypoxia problem in the Gulf of Mexico.

Keywords: agricultural policy, conservation practices, green payments, land use changes, nitrate runoff and leaching, non-point pollution, soil erosion.

ASSESSING THE COSTS AND ENVIRONMENTAL CONSEQUENCES OF AGRICULTURAL LAND USE CHANGES: A SITE-SPECIFIC, POLICY-SCALE MODELING APPROACH

Agriculture nationwide, and particularly in the Midwest, is increasingly under pressure to adopt environmentally benign land use practices. A wide range of environmental improvements have been targeted in the Midwest, including reduced soil erosion, reduced nutrient runoff from crop and livestock facilities, habitat restoration for endangered species, increased biodiversity preservation efforts, restoration of wetlands and other native ecosystems, and reduced nitrogen loading to the Gulf of Mexico and other estuaries. To achieve these targets, large-scale changes in the management of agricultural land will be needed. Possible land use changes include changing crops or rotations, altering management practices on cultivated lands, removing land from active production to create buffers, and the complete restoration of some land to its natural state. The cost and effectiveness of programs to affect such landscape changes on a regional scale is an important policy issue and is explored in this paper.

Numerous federal and state incentive-based programs have been initiated with goals of improving one or several environmental amenities, including the Conservation Reserve Program, the Environmental Quality Incentive Program, and the Wetland Reserve Program. The newly adopted Conservation Security Program expands these existing programs and includes provisions for new programs. *Ex ante* analysis of the likely cost effectiveness and environmental efficacy of changes in these programs, or ex post assessment of the outcomes of these programs, requires a large-scale economic model capable of estimating the costs of alternative land uses on spatially heterogeneous land, combined with the capacity to estimate the environmental effects of these alternative land uses on a regional scale. In addition, it is important to employ micro-level data in policy analysis, both to achieve consistency with the underlying economic theory on which land use (discrete) choice models are based and to capture accurately the significant spatial variability in economic and environmental variables (Antle and Capalbo; Just and Antle; Hochman and Zilberman).

In this paper, we present an economic model that covers a large geographic region yet is based on micro-level data and hence captures the critical choice variables and spatial variability needed to assess accurately the economic and environmental consequences of agricultural land use changes. While conceptually straightforward, the detail and breadth of this model makes it well suited to assessing agro-environmental policies that affect land use on a large scale.

The economic model is based on econometric estimates using the National Resources Inventory (NRI) data. The NRI was conducted in 1982, 1987, 1992, and 1997 and is the most comprehensive resource data ever collected in the United States. The inventories are conducted by the Natural Resources Conservation Service of the U.S. Department of Agriculture (USDA) to determine the status, condition, and trend of the nation's soil, water, and related resources. Information on nearly 200 attributes was collected at more than 800,000 sites across the continental United States. A set of micro-level, discrete choice empirical models (McFadden) is estimated using such data to predict crop choice and tillage practices at each NRI site. Environmental production functions are then used to predict nitrate runoff and leaching, water (sheet and rill) erosion, and wind erosion at each NRI site based on crop choice, tillage practices, soil characteristics, and climatic factors. Levels of these pollutants represent the site-specific environmental effects of crop production. Responses to policies designed to encourage adoption of conservation tillage and to alter crop rotations are simulated and the environmental impacts are estimated at the local level. The accumulation of local environmental impacts across the landscape affects the overall environmental quality of the region.

The study region is the Upper Mississippi River Basin, a region under scrutiny as a significant source of nutrient loadings to the Mississippi River. Such loadings are believed to be the primary cause of hypoxia in the Gulf of Mexico. The Upper Mississippi River Basin contains about 78 million acres of cropland and more than 71,000 NRI sites. Corn and soybeans are the major crops in the basin, accounting for 38 and 29 percent of cropland, respectively. Continuous corn and corn-soybean rotations are the most commonly used cropping systems in the basin, accounting for 11 and 49 percent of cropland in 1996 and 1997. Conservation tillage was used on about 30 percent of cropland in the basin. To reduce nutrient loadings from the Mississippi River Basin to the Gulf of Mexico, "green payments" have been proposed to encourage farmers to adopt conservation practices such as conservation tillage and crop rotations. The costs and environmental benefits of such incentive programs are evaluated using our empirical model. This is of significant policy interest since these programs have been proposed as part of a broad approach to reducing the hypoxic zone in the Gulf of Mexico (Mitsch et al.).

This work builds on numerous previous efforts to assess the environmental consequences of agricultural land use. Several national inventories of the status, trend, or spatial patterns of externalities from agriculture, especially as they relate to water quality, have been undertaken (Smith, Alexander, and Wolman; Mueller et al.). A few studies have evaluated water quality at the regional or national levels (e.g., Nielsen and Lee; Kellogg, Maizel, and Goss) and several other studies have examined the impact of farming practices on water pollution at the field, farm, or watershed levels (e.g., Pionke and Urban; Hallberg). Generally, these studies link the effect of cropping patterns and farming practices to water quality but do not examine how the decisions that led to these cropping patterns and farming practices were made. Thus, they are not well suited to addressing the effectiveness of incentive-based policies.

To assess incentive-based policies requires analysis of adoption decisions. Several studies have examined factors affecting the adoption of specific management practices, such as conservation tillage (Ervin and Ervin, Korsching et al.; Napier et al.; Williams, Llewelyn, Barnaby; Helms, Bailey, and Glover; Fuglie and Bosch; Kurkalova, Kling and Zhao), irrigation technologies (Caswell and Zilberman), and practices that protect water quality (Fuglie and Bosch; Wu and Babcock 1998; Cooper and Keim). Empirical studies that link adoption decisions to environmental consequences have been undertaken at the farm or watershed level (e.g., Johnson, Adams, and Perry; Helfand and House; Fleming and Adams). A few aggregate studies have investigated larger geographic regions but also take into account site-specific land characteristics (Wu and Segerson; Wu and Babcock 1999; Antle and Capalbo). Thus, there remains a need for models that combine the information embedded in more detailed micro-level data with the scale needed to assess policies that have broad-reaching geographic and environmental consequences.

In the next section, we present the components of the microeconomic behavioral model, comprised of both a crop choice and tillage practice submodel. After describing the data and variable construction, we present the econometric estimates of the behavioral model. We demonstrate the policy relevance of the model by estimating the costs and environmental benefits of incentive payments for the adoption of two types of conservation practices in the Upper Mississippi River Basin. We summarize the results and policy implications in the last section.

Modeling Framework

Within the modeling framework, a farmer is assumed to make a crop choice and tillage practice decision at an NRI site (the basic unit of analysis for this work), choosing the combination of crops and tillage practices that yields the highest expected utility. These two choices are made simultaneously; the choice of tillage practice may depend on the crop choice and vice versa. Suppose that the farmer can choose among *N* crops and conventional tillage (*o*) or conservation tillage (*c*).[1] Further, assume the farmer's utility from growing crop *i* with tillage practice *j* is $u_{ij}(X_i, Z_{j|i})$, where X_i is a vector of variables specific to the crop choice decision, including the farmer's expected profit from growing crop *i* and risks of growing crop *i* because of uncertainty about weather during the growing season, and $Z_{j|i}$ (*j* = *o* or *c*) is a vector of variables that affect the farmer's utility from adopting conservation tillage on crop *i*, including the cost differential between conservation and conventional tillage.

Because the farmer's preferences are unknown to the researcher, $u_{ij}(X_i, Z_{j|i})$ can be considered a random variable and can be written as

$$u_{ij}(X_i, Z_{j|i}) = v_{ij}(X_i, Z_{j|i}) + \varepsilon_{ij}, \quad i = 1, 2, \ldots, N, \; j = o, c. \tag{1}$$

where $v_{ij}(X_i, Z_{j|i})$ is the mean of $u_{ij}(X_i, Z_{j|i})$ and is specified as $v_{ij}(X_i, Z_{j|i}) = X_i'\beta_i + Z_{j|i}'\gamma_{j|i}$, and ε_{ij} is a random error term. If the residuals ε_{ij} are assumed to be independently and identically distributed with the extreme value distribution, then the probability that the farmer will choose crop *i* and tillage *j* is given by a multinomial logit model (Maddala, p. 60):

$$P_{ij} \equiv Prob(crop\ i,\ tillage\ j) = \frac{e^{X_i'\beta_i + Z_{j|i}'\gamma_{j|i}}}{\sum_{k=1}^{N}\sum_{m=o,c} e^{X_k'\beta_k + Z_{m|k}'\gamma_{m|k}}}, \quad i = 1, ..., N,\ j = o, c. \tag{2}$$

For estimation purposes, it is convenient to write this joint probability as the product of two components, as follows:

$$P_{ij} = \frac{e^{X_i'\beta_i + Z_{j|i}'\gamma_{j|i}}}{\sum_{m=o,c} e^{X_i'\beta_i + Z_{m|i}'\gamma_{m|i}}} \cdot \frac{\sum_{m=o,c} e^{X_i'\beta_i + Z_{m|i}'\gamma_{m|i}}}{\sum_{k=1}^{N}\sum_{m=o,c} e^{X_k'\beta_k + Z_{m|k}'\gamma_{m|k}}} \tag{3}$$

$$= \frac{e^{Z_{j|i}'\gamma_{j|i}}}{\sum_{m=o,c} e^{Z_{m|i}'\gamma_{m|i}}} \cdot \frac{\sum_{m=o,c} e^{X_i'\beta_i + Z_{m|i}'\gamma_{m|i}}}{\sum_{k=1}^{N}\sum_{m=o,c} e^{X_k'\beta_k + Z_{m|k}'\gamma_{m|k}}}$$

$$= Prob(tillage\ j \mid crop\ i) \cdot Prob(crop\ i)\ .$$

This decomposition is convenient, as it means that we can study separately the choice of crop and the choice of tillage practice, conditioned on the choice of crop:

$$Prob(conservation\ tillage | crop\ i) = \left(1 + e^{Z_{c|i}' g_{c|i}}\right)^{-1}, \tag{4}$$

where $\gamma_{o|i}$ is normalized to zero (see Greene, pp. 697-99).

The multinomial logit model has been used widely in economic analysis, including in the study of the choice of transportation modes, occupations, asset portfolios, and the number of automobiles demanded. In agriculture, it has been used to model farmers' land allocation decisions (Lichtenberg; Wu and Segerson; Hardie and Parks; Plantinga, Mauldin, and Miller), the choice of irrigation technologies (Caswell and Zilberman), and the choice of alternative crop management practices (Wu and Babcock 1998).[2]

The marginal effects of chances in explanatory variables on crop choices in a logit model are nonlinear combinations of the explanatory variables and can be written as

$$\frac{\partial P_i}{\partial X_i} = P_i\left(\beta_i - \sum_{k=1}^{N} P_k \beta_k\right), \tag{5}$$

where $P_i \equiv Prob(crop\ i)$. The sign and magnitude of this marginal effect have no direct relationship with any specific coefficient.

Data and Variable Construction

The implementation of the framework described in the last section requires a substantial amount of data, which must be integrated from multiple sources. These data include (*a*) the choice of crop and tillage at each NRI site, (*b*) farmers' expected input and output prices and government commodity programs, (*c*) expected yields, (*d*) site characteristics at each NRI point (soil properties, topographic features, climate conditions), (*e*) measures of production risks, and (*f*) site-specific production costs by crop and tillage practice. In this section, we describe the data sources and construction of the variables used in model estimation.

Time-series data on crop choice and tillage practice at each NRI site were derived from the 1982, 1987, 1992, and 1997 NRIs. The Upper Mississippi River Basin includes 71,104 NRI sites, of which 42,229 are in agricultural land. Each NRI site was assigned a weight called the xfactor to indicate the acreage it represents. For example, the sum of xfactors at all NRI sites planted to corn gives an estimate of corn acreage in the region. The sampling design ensures that inferences at the national, regional, state, and substate levels can be made in a statistically reliable manner.

Each NRI contains crop choice information for four years (the current year plus the previous three years) and tillage information for one year. Thus, we have crop choice information for sixteen years at each NRI site and tillage information for three years.[3] Pooling these time-series and cross-sectional data results in 675,664 observations for the crop choice model (42,229 agricultural NRI sites × 16 years) and 126,687 observations for the tillage model (42,229 × 3). For computational feasibility, we randomly selected 5 percent of the observations for the estimation of the crop choice and tillage models.

The expected profits and the variances of profits from growing corn and soybeans are estimated using the following formula (Bain and Engelhardt, p. 177):

$$E(\pi) = E(p)E(y) + \rho(p, y)sd(p)sd(y) - C\,, \quad (6)$$

$$V(\pi) \cong E(y)^2V(p) + E(p)^2V(y) + 2E(p)E(y)\rho(p, y)sd(p)sd(y)\,, \quad (7)$$

where p is the output price, y is the crop yield, C is the non-random production cost, and $E(\cdot)$, $V(\cdot)$, $sd(\cdot)$, $\rho(\cdot,\cdot)$ are mean, variance, standard deviation, and correlation coefficient operators, respectively. Because the production of hay is less sensitive to weather conditions, profit from growing hay is assumed to be non-stochastic and is estimated by subtracting the site-specific production costs from the expected revenue.

Several approaches have been used to estimate farmers' expected prices. Gardner, and Just and Rausser argued for the use of futures prices in acreage response analysis on rational expectations grounds as well as for forecast accuracy. Chavas and Holt used adaptive expectations and the lagged market price to model farmers' expected prices. Chavas, Pope, and Kao examined the role of futures prices, lagged market prices, and support prices in acreage response analysis. They found that since futures prices and lagged market prices are highly correlated and reflect similar market information, use of both in supply equations may lead to multicollinearity, while deleting one of the two makes little empirical difference. Shumway defined the expected price as the higher of current weighted support price and a geometric lagged function of market prices in the previous seven years. Wu and Segerson specified expected prices for program crops as the higher of the current target price and a linear function of previous years' market prices. The number of years lagged is determined using a partial autocorrelation coefficient method.

Based on these studies, the expected price for corn was specified as the higher of the weighted target price and the average futures price in the corn planting season. The weighted target price is calculated by multiplying the corn target price by the portion of corn base permitted for corn planting (i.e., 1 – Acreage Reduction Program [ARP] rate for corn). The ARP rate and target price for corn were taken from Green and other USDA publications. The average futures price for corn in its planting season was estimated as the average of the first and second Thursday closing prices in March on the Chicago Board of Trade (CBOT) for December corn. Soybeans is a non-program crop. Expected prices for soybeans were specified as the average futures prices in its planting season, which were estimated as the average of the first and second Thursday closing prices in

March on the CBOT for November soybeans. Hay is a multi-year, non-program crop. Market prices lagged one year are used as farmers' expected prices for hay. The state-level, annual average market price for hay was taken from USDA's *Agricultural Statistics*. All prices are normalized by the index of prices paid by farmers for all inputs including interest, taxes, and wages.

Crop yields at individual NRI sites are unavailable for the study region. However, the county-level, time-series crop data from the National Agricultural Statistics Service (NASS) allow us to estimate farmers' expected yields and yield variance in each county. Specifically, following Chavas and Holt, a trend model of $y = \alpha + \beta t + \varepsilon$ was estimated in each county using the NASS data from 1975 to 1997. The resulting predictions were taken as expected yields. The estimated residuals were then used to generate the variances of yields, which are assumed constant over time. The non-truncated correlation between price and yield was estimated to be –0.293 for corn and –0.149 for soybeans.

To capture the yield differences among NRI sites, physical variables reflecting land quality at individual NRI sites (land capability class, slope) are included as independent variables in the models. NRI provides information on land capability classes and land slope at each NRI site. Slope is a continuous variable measured as a percentage, while high-quality land is a category or dummy variable, defined as land with a capability class of 1 or 2. In addition, historical weather data were obtained from the Midwestern Climate Center. The mean and variance of maximum daily temperature and precipitation during corn and soybean growing seasons were estimated for each NRI site and included in the crop choice and tillage models to capture the differences in crop yields and production risks across the NRI sites.

The perceived variances of corn and soybean prices are estimated following Chavas and Holt. Specifically,

$$V(p_t) = \sum_{j=1}^{3} \omega_j \left[p_{t-j} - E_{t-j-1}(p_{t-j}) \right]^2, \tag{8}$$

where the weights ω_j are 0.5, 0.33, and 0.17; p_{t-j} is the annual average of market price for corn or soybeans in year *t-j* as reported in USDA's *Agricultural Statistics*; and E_{t-j-1} is the expectation, at planting time in year *t-j*, of the price for the crop at harvesting in year *t-j*.

Site-specific production costs, by crop and tillage practices, were developed though the use of USDA's Cropping Practices Survey data to generate statistically representative crop production systems and costs by state, crop, previous year crop, and tillage type for the entire region. The Cropping Practices Survey collects nutrient and pesticide usage and other related practice data on major field crops (corn, soybeans, wheat, and cotton). The surveys were USDA's primary source of information about the status and trends in crop production practices. The surveys yield annual data summaries for field-level data by crop, nutrient use and nutrient management practices, crop residue management practices, and pest management practices and pesticide use. The Cropping Practices Survey data can be downloaded from the Economic Research Service's web site (USDA-ERS).

Model Estimates and Interpretation

Table 1 presents the estimated coefficients of the multinomial logit crop-choice model, based on the general specification presented in equation (3). As is evident from the table, the statistical results are quite robust; the model correctly predicts the choice of crops at 67 percent of in-sample sites and 69 percent of out-of-sample sites. About half of the estimated coefficients are significant at least at the 1 percent level, and only two of the price variables are not significant at the 5 percent level. All but one of the coefficients on the land quality and slope variables are significant at the 1 percent level. For the statistically significant variables, signs are generally as expected. For example, increases in own profit raises the likelihood of farmers choosing that crop. Similarly, selection of this year's crop at a site is influenced by the previous year's crop, a reflection of rotational practices in the region. In terms of climate and land quality variables, high temperatures and large rainfall events during the corn growing season have a negative effect on the choice of corn but have a positive effect on the choice of soybeans. Corn and soybeans are more likely to be planted on high-quality land, while hay is generally relegated to low-quality land. Hay and corn are also more likely to be planted on sloped land than is soybeans because soybeans is a more erosion-prone crop.

Table 2 translates the coefficients from Table 1 into elasticities of probabilities of choosing alternative crops, using equation (5) and the means of the variables.[4] Variables of particular interest are the profit measures; because corn and soybean profits are highly

TABLE 1. Coefficient estimates for the multinomial logit crop choice model

	Corn		Soybeans		Hay	
Variables	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
Constant	-0.5890	-0.56	-11.8831***	-9.08	-1.5188	-1.13
Expected profit for corn	0.6566***	9.34	0.5851***	7.60	-0.0177	-0.17
Expected profit for hay	0.5395***	7.16	0.1291	1.54	0.3363***	3.11
Variance of corn profit	0.8724***	2.79	0.7724**	2.29	0.9468**	2.01
Previous crop is corn	2.9166***	51.09	3.6581***	57.24	0.0446	0.48
Previous crop is soybeans	3.2349***	54.33	1.4023***	20.37	-0.9799***	-6.43
Previous crop is hay	3.1768***	29.11	1.5890***	10.35	4.5319***	43.62
Mean max. temperature during corn growing season	0.0011	0.06	0.0428**	2.26	-0.0035	-0.15
Std. deviation of max. temp. during corn growing season	0.0176	0.36	0.3674***	6.74	-0.0626	-0.95
Mean min. temperature during corn growing season	-0.0423**	-2.40	0.0813***	4.06	-0.0330	-1.35
Std. deviation of min. temp. during corn growing season	0.0495	0.91	-0.2789***	-4.59	0.1340*	1.76
Mean precipitation during corn growing season	2.9955	0.90	16.0204***	4.33	-1.1733	-0.24
Std. deviation of precipitation during corn growing season	-2.0675	-1.47	-3.7793**	-2.46	3.4943	1.65
High-quality land	0.4573***	10.06	0.6308***	12.52	0.1991***	3.03
Slope	-0.0017***	-2.70	-0.0124***	-15.33	0.0007	0.85
Dummy for IL	0.0463	0.63	0.1272	1.58	-0.2482**	-2.21
Dummy for IN	0.2222*	1.66	-0.0627	-0.44	-0.4213*	-1.78
Dummy for MO	-0.8436***	-7.49	0.1369	1.21	-0.3580**	-2.22
Dummy for MI	-0.6134***	-7.81	-0.0836	-0.97	-0.3416***	-2.97
Dummy for WI	-0.2746***	-3.02	-1.7511***	-14.56	0.2084*	1.74
Total number of observations used in estimation			27,337			
Percentage of correct prediction – in sample [a]			67%			
Percentage of correct prediction – out of sample [b]			69%			

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.
[a]The sample includes all observations used in the estimation.
[b]The sample includes the 42,229 agricultural NRI points. The predicted crop choices for 1997 are compared with the 1997 NRI data.

correlated in the study region, only the expected profit for corn is included in the model. As previously noted, increased profit has a positive effect on the choice of each crop. For example, an increase in the profit from corn and soybeans increases the probability that corn and soybeans will be planted but reduces the probability that hay will be planted. Likewise, increased profit from hay has a positive effect on the choice of hay but a negative effect on the choice of soybeans. The positive effect of increased profit from hay

TABLE 2. Estimated elasticities of probabilities for choosing alternative crops

	Corn		Soybeans		Hay	
	Elasticity	**t-statistic**	**Elasticity**	**t-statistic**	**Elasticity**	**t-statistic**
Expected profit for corn	0.2238***	7.94	0.1492***	3.65	-0.4798***	-5.75
Expected profit for hay	0.1579***	7.87	-0.1240***	-4.18	0.0183	0.31
Variance of corn profit	0.0255	1.41	0.0100	0.39	0.0370	0.64
Previous crop is corn	0.2753***	21.81	0.5926***	33.15	-0.9534***	-28.76
Previous crop is soybeans	0.4331***	45.67	-0.0695***	-5.26	-0.7228***	-20.22
Previous crop is hay	0.0937***	16.31	-0.0913***	-8.45	0.2517***	35.70
Mean max. temperature during corn growing season	-0.8465	-1.55	2.4145***	2.93	-1.1994	-0.80
Std. deviation of max. temp. during corn growing season	-0.8043***	-4.22	2.5429***	8.87	-1.5710***	-3.11
Mean min. temperature during corn growing season	-2.3409***	-5.92	4.4566***	7.44	-1.8274*	-1.71
Std. deviation of min. temp. during corn growing season	0.8644***	3.99	-2.3311***	-7.27	1.6868***	2.85
Mean precipitation during corn growing season	-0.3260**	-1.93	1.3145***	5.33	-0.8510*	-1.70
Std. deviation of precipitation during corn growing season	-0.1775	-1.02	-0.7117***	-2.86	1.5583***	2.92
High-quality land	0.0380***	3.25	0.1462***	8.53	-0.1229***	-3.72
Slope	0.0642***	8.43	-0.2230***	-17.05	0.1272***	7.34

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

on the choice of corn may reflect the fact that the corn-hay rotation is a profitable cropping system in the region. Corn acreage is the most responsive to profit changes, while hay is the least responsive (because hay is a perennial crop typically relegated to lower-quality land). However, consistent with previous studies, all price elasticities are inelastic. Thus, crop choice in the study region is relatively unresponsive to changes in the price variables. This is not surprising, in view of agronomic (rotational) constraints and the relatively few crops grown in the study region. To capture the differences across the states in the region that are not reflected by the independent variables (e.g., cultural practices), state dummies are used in the models. Most of the state dummies are statistically significantly at the 10 percent level.

The elasticities of the land quality variables indicate that high-quality land (Natural Resources Conservation Service [NRCS] soil classes I and II) are more likely to be planted to high-valued crops (e.g., corn and soybeans) than to hay. In contrast, land with steeper slopes is more likely to be allocated to other crops (e.g., hay) than to erosion-prone soybeans. Finally, if the previous year's crop is corn, farmers are more likely to grow corn or soybeans; however, if the previous crop is soybeans, farmers are more likely to grow corn but less likely to grow soybeans. These results reflect the fact that continuous corn and a corn-soybean rotation are the most popular cropping systems in the study region, while growing continuous soybeans is not widely practiced.

The other choice model in this framework is the farmers' choice of tillage practices. Table 3 presents the estimated coefficients for the logistic tillage choice model and the elasticities for the non-dummy variables. Overall, the model performs well; it correctly predicts the adoption of alternative tillage practices at 75 percent of the sample points. About two-thirds of the coefficients and elasticities are statistically significant at the 1 percent level. A variable of particular interest is the difference in production costs among tillage practices. Since tillage practice does not have an appreciable effect on crop yields in the short run (Vetsch and Randall; Ashraf et al.), the differences in costs play the same role in the tillage choice model as do the profits in the crop choice model. As expected, the less costly is conservation tillage relative to conventional tillage, the more likely it is that farmers will adopt conservation tillage. This result holds for both corn and soybeans. Also, the positive coefficients on high-quality land and slope are also as expected because conservation tillage is more likely to be adopted on sloped, high-quality land. However, the coefficient on the slope variable is not statistically significant at the 10 percent level.

Environmental Production Functions

Economic incentives such as green payments have the potential to change the choice of crop, rotations, and tillage practices at some NRI sites. These changes in turn will affect soil erosion, chemical runoff, and leaching at these points. We use environmental production functions to predict changes in such agricultural externalities at these NRI sites. The environmental production functions are estimated using a metamodeling approach (Wu and Babcock 1999). Specifically, for a sample of NRI points, the Erosion

TABLE 3. Coefficient estimates for the logit tillage choice model

Variables	Coefficient	t-statistic	Elasticity	t-statistic
Constant	-12.0773***	-5.75		
Difference in prod. costs of corn between conventional and conservation tillage×dummy for corn	5.1614***	9.74	0.3392***	9.74
Difference in prod. costs of soybeans between conventional and conservation tillage×dummy for soybeans	3.1022***	4.40	0.1448***	4.40
Mean max. temperature during corn growing season	0.0763***	2.72	4.4866***	2.72
Std. deviation of max. temperature during corn growing season	0.3740***	4.78	2.6897***	4.78
Mean min. temperature during corn growing season	-0.0285	-1.01	-1.1790	-1.01
Std. deviation of min. temperature during corn growing season	-0.0490	-0.56	-0.3588	-0.56
Mean precipitation during corn growing season	-18.1523***	-3.36	-1.7325***	-3.36
Std. deviation of precipitation during corn growing season	5.3103**	2.50	1.2486**	2.50
Expected yield of corn	0.0325***	10.73	2.5527***	10.73
Expected variation of corn yield	0.0010***	4.18	0.3488***	4.18
Expected price for corn	17.9834	1.33	0.1899	1.33
High-quality land	0.1890**	2.53	0.0903**	2.53
Slope	0.0004	0.35	0.0094	0.35
Dummy for IL	-0.4197***	-3.79		
Dummy for IN	-0.2214	-1.31		
Dummy for MO	-1.1675***	-5.34		
Dummy for MI	-1.3738***	-11.31		
Dummy for WI	-1.6270***	-7.77		
Total number of observations used in stimation:		6,851		
Log of likelihood function		-3342		
Percentage of correct predictions – in sample		75%		

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Productivity Impact Calculator (EPIC) (Sharpley and Williams) is used to simulate environmental impacts based on crop management practices (crop rotation, tillage, and conservation practices), soil characteristics, and climatic factors at that site. Environmental production functions are estimated by regressing the simulated environmental data (e.g., measures of nitrate runoff and leaching) on the vector of crop management practices and site characteristics. The estimated equations are then used to predict environmental impacts at the full set of NRI points. Metamodeling is required because it is infeasible to simulate environmental impacts at all sites and for all sets of conditions that arise in a large regional analysis such as the one performed here.

The nitrate-N runoff and leaching production functions are taken from Wu and Babcock 1999. The methodology used to develop the water and wind erosion production functions, similar to those used in this analysis, is described in Lakshminarayan, Babcock, and Ogg. Environmental production functions of the type used here have been applied in Gassman et al. and in Wu and Babcock 1999.

The site-specific impacts measured at each NRI site are aggregated to the polygon and regional level using the acreage expansion factors provided in the NRI dataset. The polygons represent unique intersections of county, major land resource area, and hydrologic unit boundaries and are the least aggregated level at which NRI data can be reported. Figure 1 provides a map showing the polygons representing the Upper Mississippi River Basin. As the map indicates, the model covers a large portion of total agricultural land in Iowa, Illinois, Minnesota, Missouri, and Wisconsin.

An Application: Green Payments to Reduce Nonpoint Pollution in the Upper-Mississippi River Basin

The preceding sections describe a set of crop choice and environmental performance models that collectively form an assessment framework. We applied this framework to evaluate the costs and environmental efficacy of some commonly suggested conservation practices for reducing nonpoint source pollution. Specifically, we analyze changes in the

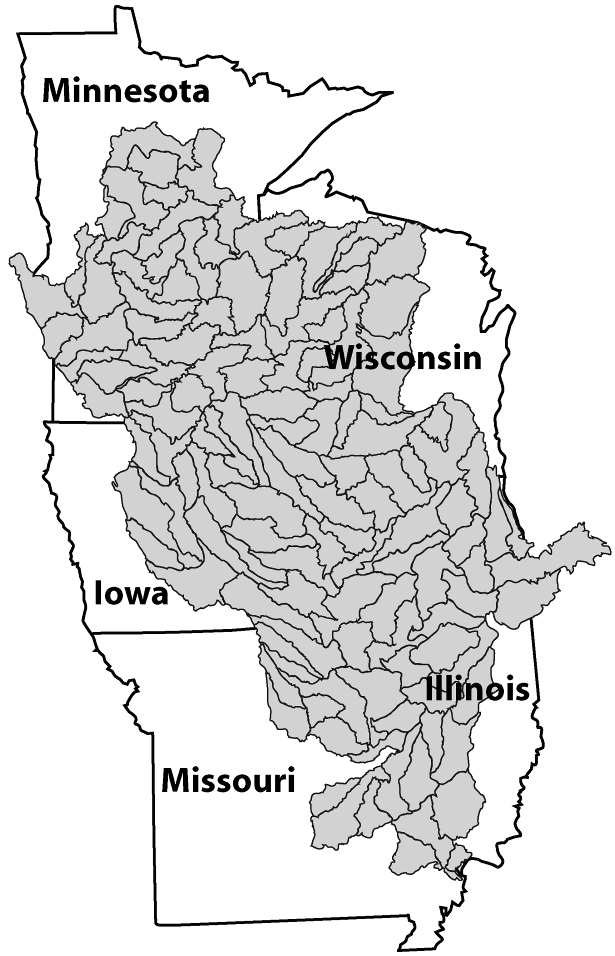

FIGURE 1. The Upper Mississippi River Basin

adoption of crop rotations (i.e., from conventional continuous corn practices to a corn-soybean rotation) and conservation tillage under a range of conservation payment levels. These changes in conservation practices are then translated into corresponding changes in nonpoint pollution (e.g., nitrate leaching and runoff, water and wind erosion) in the Upper Mississippi River Basin. Results are generated for acreages under each conservation practice at varying levels of incentive payments and for associated changes in per acre and total amounts of soil erosion, and nitrate leachate and runoff for the region.

To estimate the effect of green payments, the estimated crop and tillage models are first used to predict crop choice and tillage practices at each NRI site in 1998 and 1999 without these incentive payments. The predictions serve as a baseline or reference for measuring the effect of the incentive payment programs. Specifically, by substituting farmers' expected prices and costs for 1998 and 1999 into the crop and tillage models, the probabilities of the farmers' choices of crops and tillage practices in 1998 and 1999 are calculated for each NRI point. The total acres of each crop and total conservation tillage acres are then estimated using the following equations:

$$A_i = \sum_{k=1}^{K} Prob(\,crop\ i\,)_k * xfactor_k\ ,\ \ i = 1, 2,\ldots, N \tag{9}$$

$$A_{conserv} = \sum_{k=1}^{K}\sum_{i=1}^{N} Prob(conservation\ tillage|crop\ i)_k * Prob(crop\ i)_k * xfactor_k\ , \tag{10}$$

where $k = 1, 2,\ldots K$ is an index of NRI sites, A_i is the total acreage of crop i in the region, and $A_{conserv}$ is the total acreage under conservation tillage.

Continuous corn and corn-soybean rotations are the major cropping systems in the study region. Based on farmers' crop choices at each NRI point in 1998 and 1999, the probabilities of adopting alternative cropping systems at each NRI site are estimated using the following formula:

$$\begin{aligned} Prob(continuous\ corn)_k = {} & Prob(corn\ in\ 98 \mid crop\ choice\ in\ 97)_k \\ & *Prob(corn\ in\ 99 \mid corn\ in\ 98)_k \end{aligned}; \tag{11}$$

$$\begin{aligned} Prob(corn\text{-}bean\ rotation)_k = {} & Prob(corn\ in\ 98 \mid crop\ choice\ in\ 97)_k \\ & *Prob(soyb\ in\ 99 \mid corn\ in\ 98)_k \\ & +Prob(soyb\ in\ 98 \mid crop\ choice\ in\ 97)_k \\ & *Prob(corn\ in\ 99 \mid Soyb\ in\ 98)_k \end{aligned}. \tag{12}$$

Based on the crop rotation at each NRI point, the acreage of land under a corn-soybean rotation is then estimated as follows:

$$A_{corn-bean\ rotation} = \sum_{k=1}^{K} Prob(corn\text{-}soyb\ rotation)_k * xfactor_k\ . \tag{13}$$

Acres of continuous corn and continuous soybeans are estimated in a similar way.

Estimates from equations (9) through (13) without green payments serve as the baseline predictions. The probabilities of choosing alternative crops and tillage are then reestimated under alternative levels of conservation payments. These results are compared with the baseline acres to determine the effect of such payments. In this study, two conservation payments are simulated, one for adopting crop rotations (corn-soybean rotation) and one for adopting conservation tillage. Fertilizer runoff from agricultural lands in the Mississippi River Basin contributes nearly one-third of the annual nitrogen inputs to the Mississippi-Atchafalaya River Basin (Mitsch et al.). Reducing fertilizer use or runoff through conservation practices such as crop rotation and reduced tillage is the most commonly suggested on-site approach for reducing nutrient loadings, and hence the hypoxia problem, in the Gulf of Mexico.

In the incentive payment programs for crop rotations, farmers adopting a corn-soybean rotation are assumed to receive a payment. Specifically, farmers who grow soybeans after corn or corn after soybeans receive a payment. The effects of the payments are simulated by increasing the expected profit for the eligible crops in the crop choice model (soybeans after corn or corn after soybeans) by the amount of the payments. In the payment program for conservation tillage, farmers adopting conservation tillage also receive a payment. The effect of this payment is simulated by increasing the difference between the production costs for conventional tillage and conservation tillage in the tillage model by the amount of the conservation payments.

The effects of alternative incentive payments on the adoption of crop rotations are presented in Table 4. Table 5 reports the effects of the same levels of incentive payments on the adoption of conservation tillage practices. Multiplying the payment rates by the total acreages in Tables 4 and 5 gives the total costs of the incentive programs. A common, and expected, pattern displayed in the tables for both practices is increasing levels of adoption under higher payment levels. However, the effect of such incentives is very small for the adoption of corn-soybean rotations. For example, a payment level of $25 per acre is required before any change in rotations occurs. At that payment level, total acreage in corn-soybean rotation increases by only 1 percent. The rate of acreage response for conservation tillage practices is more elastic; a $25-per-acre incentive payment increases the adoption rate for corn by 29 percent, and by 20 percent for soybeans.

The consequences of these changes in rotations and conservation tillage practices for nitrate leaching and runoff and for water and wind erosion are reported in Tables 6 and 7.

TABLE 4. Estimated effects of green payments for corn-soybean rotation on crop rotations and acreage

	1998 and 1999 Corn and Soybean Acres in						Crop Acreage in 1998			
	Continuous Corn		Continuous Soybeans		Corn-soybean Rotation		Corn		Soybeans	
Payment $/Acre	1,000 Acres	Percent	1,000 Acres	Percent	1,000 Acres	Percent	1,000 Acres	Percent	1,000 Acres	Percent
0	9151	32	2099	7	12275	44	18613	66	9550	34
5	9191	33	2074	7	12286	44	18603	66	9582	34
10	9153	32	2069	7	12371	44	18592	66	9614	34
15	9115	32	2064	7	12456	44	18582	66	9647	34
20	9083	32	2052	7	12541	44	18571	66	9679	34
25	9052	32	2037	7	12627	45	18561	66	9712	34
30	9017	32	2028	7	12712	45	18549	66	9744	34
35	8993	32	2005	7	12798	45	18538	65	9777	35
40	8971	32	1980	7	12884	45	18527	65	9810	35
45	8936	32	1968	7	12971	46	18515	65	9843	35
50	8900	31	1957	7	13059	46	18503	65	9876	35
100	8544	30	1816	6	13949	49	18373	64	10209	36

TABLE 5. Estimated acres of crops under conservation tillage in 1998 at different payment levels

	Corn under Conservation Tillage		Soybean under Conservation Tillage		All Crops under Conservation Tillage	
Payment ($/acre)	1,000 Acres	Percent	1,000 Acres	Percent	1,000 Acres	Percent
0	7,389	41	4,069	40	13,787	34
5	7,841	43	4,232	41	14,401	36
10	8,294	46	4,396	43	15,019	37
15	8,748	48	4,562	44	15,639	39
20	9,201	51	4,728	46	16,257	40
25	9,649	53	4,895	48	16,872	42
30	10,091	56	5,061	49	17,481	43
35	10,526	58	5,228	51	18,082	45
40	10,951	60	5,394	53	18,674	46
45	11,366	63	5,560	54	19,254	48
50	11,769	65	5,724	56	19,821	49
100	15,015	83	7,244	71	24,587	61

TABLE 6. Simulated effects of green payments for corn-soybean rotation on non-point pollution in the Upper Mississippi River Basin

	N Leaching		N Runoff		Wind Erosion		Water Erosion	
Payment ($/ac)	Average (lb/ac)	Total (1k lbs)	Average (lb/ac)	Total (1k lbs)	Average (tons/ac)	Total (1k tons)	Average (tons/ac)	Total (1k tons)
0	3.47	238,959	1.69	116,542	0.16	10,691	3.06	210,752
5	3.46	238,215	1.69	116,654	0.15	10,622	3.06	210,765
10	3.45	237,430	1.70	116,796	0.15	10,595	3.06	210,769
15	3.43	236,512	1.70	116,919	0.15	10,594	3.06	210,776
20	3.42	235,669	1.70	117,030	0.15	10,596	3.06	210,782
25	3.40	234,588	1.70	117,272	0.15	10,545	3.06	210,810
30	3.39	233,435	1.71	117,686	0.15	10,483	3.06	210,829
35	3.36	231,588	1.71	117,967	0.15	10,456	3.06	210,838
40	3.35	230,807	1.72	118,423	0.15	10,382	3.06	210,861
45	3.34	230,032	1.72	118,630	0.15	10,338	3.06	210,864
50	3.31	228,309	1.73	118,955	0.15	10,340	3.06	210,875

Note: ac indicates acre; k indicates 1,000.

TABLE 7. Simulated effects of green payments for conservation tillage on non-point pollution in the Upper Mississippi River Basin

	N Leaching		N Runoff		Wind Erosion		Water Erosion	
Payment ($/ac)	Average (lb/ac)	Total (1k lbs)	Average (lb/ac)	Total (1k lbs)	Average (tons/ac)	Total (1k tons)	Average (tons/ac)	Total (1k tons)
0	3.47	238,959	1.69	116,542	0.16	10,691	3.06	210,752
5	3.48	239,702	1.68	115,929	0.14	9,988	3.01	207,185
10	3.50	241,312	1.67	114,758	0.13	9,121	2.91	200,246
15	3.51	242,040	1.66	114,161	0.13	8,773	2.82	194,480
20	3.52	242,707	1.65	113,487	0.12	8,421	2.75	189,798
25	3.53	243,159	1.64	113,122	0.12	8,099	2.72	187,351
30	3.53	243,486	1.64	112,872	0.12	7,996	2.69	185,526
35	3.54	243,869	1.63	112,479	0.11	7,740	2.66	183,422
40	3.54	244,090	1.63	112,279	0.11	7,614	2.64	182,204
45	3.55	244,289	1.63	112,089	0.11	7,487	2.63	181,156
50	3.55	244,458	1.62	111,876	0.11	7,354	2.62	180,361

Note: ac indicates acre; k indicates 1,000.

Table 6 provides the changes in per acre and total amounts of the four nonpoint pollution measures, by incentive payment level, for the adoption of a corn-soybean rotation. Under this practice, leached nitrate and wind erosion averages per acre fall slightly, while the average nitrate runoff per acre increases slightly. Average water erosion shows little change. Thus, a shift toward a corn-soybean rotation is likely to have beneficial effects on groundwater quality but negative effects on surface water. However, the overall changes in the four pollution measures are small; at the $50 payment level, leached nitrate and wind erosion totals are reduced by only 4.5 percent and 3.3 percent, respectively, while total wind runoff for the region increases by about 2 percent.

The effects of payments for adoption of conservation tillage on these four pollution measures are presented in Table 7. Here, the effect on nitrate runoff and leaching is the opposite of that observed for the adoption of crop rotations. Specifically, under the increased use of conservation tillage, the amount of leached nitrogen increases, while the amount of nitrate runoff is reduced. This outcome is consistent with the slowing of water movement across the field because of increased vegetative cover. As was the case with crop rotations, the net effect, as measured by a percentage change in total amounts of leached nitrate and nitrate runoff, are quite small: less than a 3 percent increase in leached nitrate and a 4 percent reduction in nitrate runoff for a $50-per-acre incentive payment. The small changes in per acre and total nitrogen under the varying practices at relatively high incentive payment levels is attributable to three factors: the limited number of crop choices in the Upper Mississippi River Basin, the relatively small change in nitrogen levels (both leachate and runoff) between the conservation practices evaluated here and conventional practices, and the averaging over all crops grown in the Upper Mississippi River Basin. Green payments for conservation tillage are more effective in reducing soil erosion than in reducing nitrate water pollution. At the $50 payment level, total wind and water erosion are reduced by 31 percent and 14 percent, respectively.

The environmental performance of one of the conservation payment programs is portrayed on a geographical scale in Figure 2. Specifically, Figure 2 depicts the changes in potential water pollution from soil erosion and nitrate runoff and leaching that arise from a green payment of $50 for adoption of conversation tillage. As expected, the pattern of changes varies across the basin and reflects soil and topographical characteristics, as well as cropping patterns. For example, the areas of greatest change in nitrate leachate and runoff occur in Iowa and Illinois, areas of high nitrogen application, intensive cropping of corn, and deep soils. The areas of a greatest change in wind erosion follow the soil and wind patterns of the region, with western areas of the basin experiencing the greatest benefit from conservation tillage. Water erosion tends to occur along the mainstems of

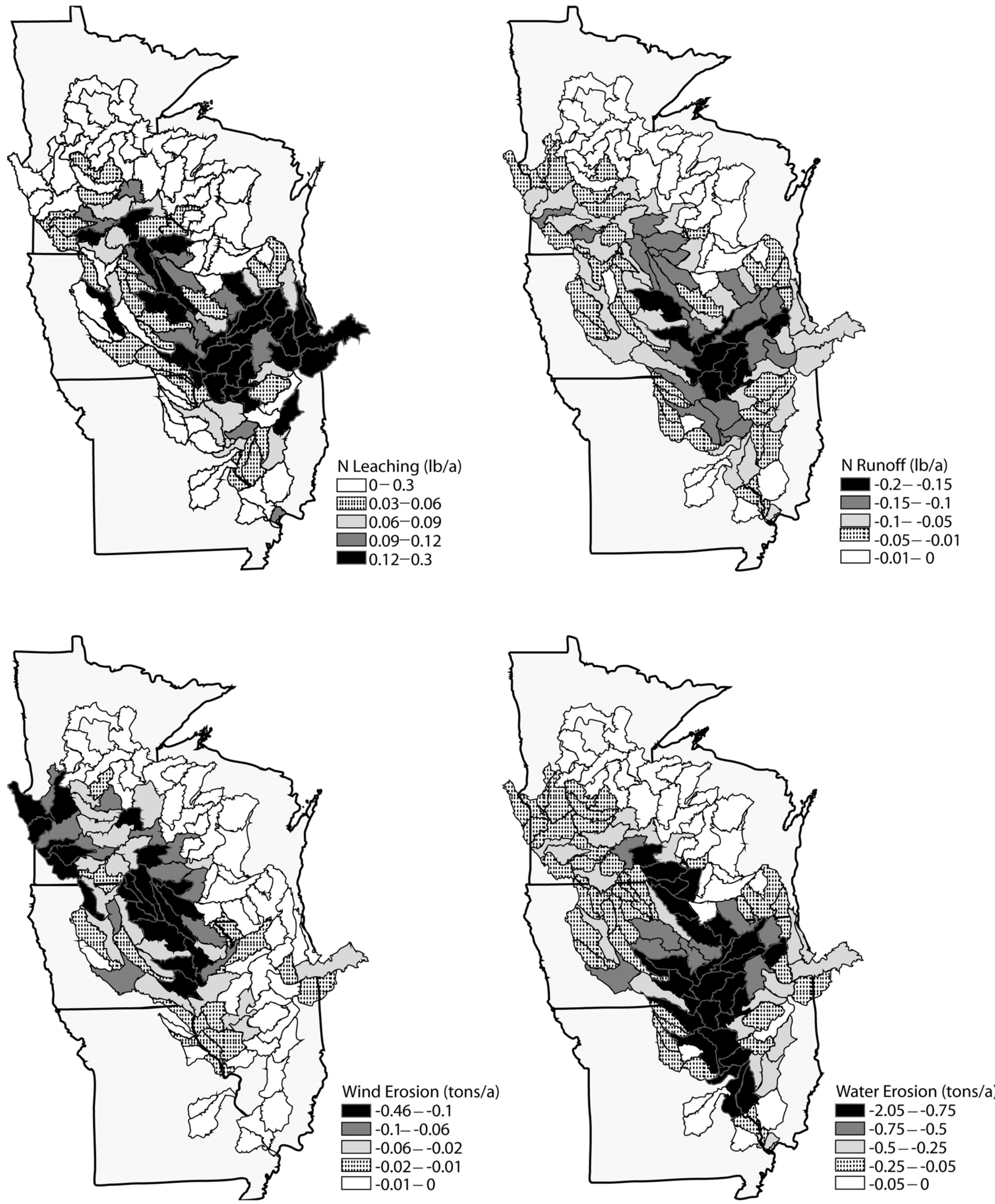

FIGURE 2. Estimated changes in nonpoint pollution under green payments for conservation tillage ($50/acre)

the Mississippi and its tributaries; the benefits of conservation tillage reflect topography (areas of slope greater than 5 percent) and a higher percentage of corn in the crop rotation in these areas.

Figure 2 should be viewed as demonstrating the utility of the modeling framework to provide general patterns of responses in these environmental variables across the landscape, not in forecasting actual environmental performance for each polygon. As noted elsewhere, these patterns reflect the relative variability in soils, slope, and cropping systems found across the polygons of the Upper Mississippi River Basin. The magnitude of the changes in nitrate leachate and runoff, as well as soil erosion, are driven by the crop choice models and the level of incentive payments imposed on the model simulations.

In sum, the marginal cost curves associated with reducing nitrogen pollution through conservation tillage or changing crop rotations in the Upper Mississippi River Basin are nearly vertical. This finding suggests that the costs of these two policies as a means of reducing nutrient loadings and hypoxia problems in the Gulf of Mexico are likely to be very high relative to the environmental benefits. The policy implications of these findings are important. Specifically, the potential for addressing hypoxia and other water quality problems in this region through use of these practices is limited. Instead, policymakers should consider other conservation alternatives, such as land retirement, reduction in nitrogen applications, or changes in the timing and methods of nitrogen applications, to reduce nitrate runoff from the Upper Mississippi River Basin. However, policies evaluated here do have merits in terms of reducing soil erosion in the basin.

Concluding Comments

The 2002 federal farm legislation contains a substantial increase in funding for conservation initiatives. Critics argue that many programs in the farm bill are political payments, and that there is little evidence that these incentive payments are cost effective. As the debate over future agricultural policy continues, it is important for policymakers and other interest groups to have reliable and timely information on the relationships between agricultural practices and environmental conditions and how these relationships may be affected by changes in agricultural and resource policies.

This study presents an empirical modeling framework designed to assess the environmental and economic effects of incentive programs over a large area of the Midwest (all of the Upper Mississippi River Basin). The empirical models predict crop choices, crop rotations, and the adoption of conservation tillage practices at more than 42,000 National Resource Inventory sites based on the level of conservation payments, profits, and variances of profits, as well as land quality, climate conditions, and other physical characteristics at each of the sites. The changes in crop choices and tillage practices are then combined with site-specific environmental production functions to determine the effect of conservation payments on nitrate runoff and leaching and on water and wind erosion at each NRI site. The modeling framework's predictive ability of crop and tillage choice decisions (out of sample) is strong by standard statistical measures. Prediction of the effects of green payments on environmental performance, however, is less reliable, given the nature of the underlying environmental production functions. Even here, the results conform to estimates found in other regionally focused studies.

We present a case study focusing on the important issue of the costs and environmental consequences of reducing nitrate and soil loadings in the Upper Mississippi River Basin. The results suggest that conservation payments can increase the use of crop rotations and conservation tillage in the region. However, the acreage response is inelastic. More importantly, the effect on nitrate runoff and leaching is quite small, implying high marginal costs for reducing nitrate water pollution. These results provide information about the effect of incentive payments on the supply of environmental goods from agriculture, as well as an assessment of a commonly suggested approach for controlling hypoxia in the Gulf of Mexico. Findings from this assessment indicate that adoption of conservation practices such as conservation tillage and crop rotations are not likely to be effective methods on their own for reducing nutrient loadings in the Gulf of Mexico. These practices do show promise in terms of reducing soil erosion and hence may have more local water quality benefits.

Endnotes

1. Conservation tillage is one component of conservation through crop residual management (USDA-ERS). Conservation tillage is defined as leaving more than 30 percent of crop residual, and includes mulch-till (soil is not disturbed prior to planting), ridge-till (residual left on the surface between tilled ridges), and no-till (no tillage performed). The 1982 and 1992 NRI data only allow us to identify whether conventional or conservation tillage is used at each NRI point.

2. An often-cited limitation of the multinomial logit model is the assumption of independence of irrelevant alternatives. This assumption imposes a restriction that the relative choice probabilities for any two alternatives are independent of the other choices available. This property is convenient for estimation but legitimate only if there are no omitted variables in estimation, as omitted variables that are correlated across the choice will result in its violation. Nested logit models are a commonly employed way to relax this assumption, but they require that the analyst impose the correlation pattern *ex ante*. Multinomial probit models are no panacea either as restrictions on the variance-covariance matrix must also be imposed before estimation.

3. The 1997 NRI data used here contained crop information but not tillage information.

4. To determine the effect of land quality and other dummy variables on the choice of crops and tillage practices, we calculate elasticities with respect to these dummy variables as if they were continuous. Specifically, the following formula is used to calculate the elasticities with respect to these dummy variables:

$$\varepsilon \equiv \frac{\partial P_i}{\partial D}\frac{\overline{D}}{P_i} = \overline{D}\left(\hat{\beta}_i^D - \sum_{k=1}^{N} \hat{P}_k \hat{\beta}_k^D\right),$$

where $\overline{D}$ is the mean of D in the sample (i.e., the percentage of NRI points where D=1), and $\hat{\beta}_i^D$ is the coefficient on D in equation i. It is necessary to calculate these elasticities because the sign of the coefficients on these dummy variables does not indicate how land quality or other dummy variables affect crop and tillage choices.

References

Antle, J.M., and S.M. Capalbo. "Econometric-Process Models for Integrated Assessment of Agricultural Production Systems." *Amer. J. Agr. Econ.* 83(2001):389-401.

Ashraf, M., C.H. Pearson, D.G. Westfall, and R. Sharp. "Effect of Conservation Tillage on Crop Yields, Soil Erosion, and Soil Properties under Furrow Irrigation in Western Colorado." *Amer. J. Altern. Agr.* 14(1999):85-92.

Bain, L.J., and M. Engelhardt. *Introduction to Probability and Mathematical Statistics*. Belmont, CA: Duxbury Press, 1992.

Caswell, M., and D. Zilberman. "The Choice of Irrigation Technologies in California." *Amer. J. Agr. Econ*. 67(1985):224-34.

Chavas, J-P., and M.T. Holt. "Acreage Decisions Under Risk: The Case of Corn and Soybeans." *Amer. J. Agr. Econ.* 72(August 1990):529-38.

Chavas, J-P., R.D. Pope, and R.S. Kao. "An Analysis of the Role of Future Prices, Cash Prices, and Government Programs in Acreage Response." *West. J. Agr. Econ*. 8(1983):27-33.

Cooper, J.C., and R.W. Keim. "Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices." *Amer. J. Agr. Econ.* 78(1996):54-64.

Ervin, C.A., and D.E. Ervin. "Factors Affecting the Uses of Soil Conservation Practices: Hypotheses, Evidence, Policy Implications." *Land Econ.* 58(1982):277-92.

Fleming, R., and R.M. Adams. "The Importance of Site-Specific Information in the Design of Policies to Control Pollution." *J. of Environ. Econ. & Manage.* 33(1997):347-358.

Fuglie, K.O., and D.J. Bosch. "Economic and Environmental Implication of Soil Nitrogen Testing: A Switching-Regression Analysis." *Amer. J. Agr. Econ*. 77(1995):891-900.

Gardner, B.L. "Futures Prices in Supply Analysis." *Amer. J. Agr. Econ.* 58(1976):81-84.

Gassman, P.W., J.J. Wu, P. Mitchell, B.A. Babcock, T.M. Hurley, and S.W. Chung. "Impact of U.S. Agricultural Policy on Regional Nitrogen Losses." In *Proceedings of the 3rd International Conference on Diffuse Pollution* (Poster Papers), 31 Aug. - 4 Sept., Edinburgh, Scotland. International Association of Water Quality, London, England. pp. 115-22.

Green, R.C. "Program Provisions for Program Crops: A Database for 1961-90." Agriculture and Trade Analysis Division, Economic Research Service, U.S. Department of Agriculture. Staff Report No. AGES 9010. March 1990.

Greene, W.H. *Econometric Analysis*. New York: Macmillan Publishing Company, 1993.

Hallberg, G.R. "Nitrate in Ground Water in the United States." In *Nitrogen Management and Ground-Water Protection*, R.F. Follet, ed., pp. 35-74. New York: Elsevier Science Publishing Co., 1989.

Hardie, I.W. and P.J. Parks, "Land Use with Heterogeneous Land Quality: An Application of an Area Base Model." *Amer. J. Agr. Econ.* 79 (1997):299-310.

Helfand, G.E., and B.W. House. "Regulating Nonpoint Source Pollution Under Heterogeneous Conditions." *Amer. J. Agr. Econ.* 77(1995):1024-32.

Helms, G.L., D.V. Bailey, T.F. Glover. "Government Programs and Adoption of Conservation Tillage Practices on Nonirrigated Wheat Farms." *Amer. J. Agr. Econ*. 69(1987):786-95.

Hochman, E., and D. Zilberman. "Examination of Environmental Policies Using Production and Pollution Microparameter Distribution." *Econometrica* 46(1978):739-60.

Johnson, S.L., R.M. Adams, and G.M. Perry. "The On-Farm Costs Of Reducing Groundwater Pollution." *Amer. J. Agr. Econ.* 73(1991):1063-72.

Just, R.E., and J.M. Antle. "Interactions Between Agricultural and Environmental Policies: A Conceptual Framework." *Amer. Econ. Rev.* 80(1990):197-202.

Just, R.E., and G.C. Rausser. "Commodity Price Forecasting with Large-Scale Econometric Models and the Futures Market." *Amer. J. Agr. Econ.* 63(1981):197-207.

Kellogg, R.L., M.S. Maizel, and D.W. Goss. "Agricultural Chemical Use and Groundwater Quality: Where Are the Potential Problem Areas?" The Soil Conservation Service, U.S. Department of Agriculture, Washington D.C., December 1992.

Korsching, P.F., C.W. Stofferahn, P.J. Nowak, and D. Wagener. "Adoption Characteristics and Adoption Patterns of Minimum Tillage: Implications for Soil Conservation Programs." *J. Soil and Water Conserv.* 38(1983):428-30.

Kurkalova, L.A., C.L. Kling, and J. Zhao. "The Subsidy for Adopting Conservation Tillage: Estimation from Observed Behavior." CARD Working Paper 01-WP 286, Center for Agricultural and Rural Development, Iowa State University. September 2001.

Lakshminarayan, P.G., B.A. Babcock, and C. Ogg. "Temporal and Spatial Evaluation of Soil Conservation Policies." CARD Working Paper 96-WP 149, Center for Agricultural and Rural Development, Iowa State University. February 1996.

Lichtenberg, E. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *Amer. J. Agr. Econ.* 71(1989):187-94.

Maddala, G.S. *Limited-Dependent and Qualitative Variables in Econometrics.* Cambridge: Cambridge University Press, 1983.

McFadden, D. "Quantal Choice Analysis: A Survey." *Annals of Econ. & Social Measur.* 5(1976):363-90.

Mitsch, W.J., J.W. Day, Jr., J.W. Gilliam, P.M. Groffman, D.L. Hey, G.W. Randall, and N. Wang. "Reducing Nitrogen Loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to Counter a Persistent Ecological Problem." *BioScience* 51(2001):373-88.

Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy. "Nutrients in Ground Water of the United States—An Analysis of Data Through 1992." Water-Resources Investigations Rep. No. 95-4031. U.S. Geological Survey, Denver, CO, 1995.

Napier, T.L., C.S. Thraem, A. Gore, and W.R. Goe. "Factors Affecting Adoption of Conventional and Conservation Tillage Practices in Ohio." *J. Soil and Water Conserv.* 39(1984):205-8.

Nielsen, E.G., and L.K. Lee. "The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals: A National Perspective." U.S. Department of Agriculture, Washington D.C.; Economic Research Services, Agricultural Economic Report No. 576, October 1987.

Pionke, H.B., and J.B. Urban. "Effect of Agricultural Land Use on Ground-Water Quality in Small Pennsylvania Watershed." *Ground Water* 23(1985):68-80.

Plantinga, A.J., T. Mauldin, and D.J. Miller. "An Econometric Analysis of the Cost of Sequestering Carbon in Forests." *Amer. J. Agr. Econ.* 81(1999):812-24.

Sharpley, A.N., and J.R. Williams, eds. 1990. *EPIC--Erosion/Productivity Impact Calculator: 1. Model Documentation.* Tech. Bull. No. 1768, U.S. Department of Agriculture, Washington, D.C.

Shumway, C.R. "Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops." *Amer. J. Agr. Econ.* 65(1983):748-60.

Smith, R.A., R.B. Alexander, and M.G. Wolman. "Water Quality Trends in the Nation's Rivers." *Science* 235(1987):1607-15.

U.S. Department of Agriculture (USDA). *Agricultural Statistics*. Various. Washington, D.C.: U.S. Department of Agriculture, 1975-1999.

U.S. Department of Agriculture, Economic Research Service (USDA-ERS). "1995 Cropping Practices Survey Data (93018F)." *http://www.ers.usda.gov/data/sdp/view.asp?f=inputs/93018/F/* (accessed March 2003).

Vetsch, J.A., and G.W. Randall. "Corn Production as Affected by Tillage System and Starter Fertilizer." *Agron. J.* 94(2002):532-40.

Williams, J.R., R.V. Llewelyn, and G.A. Barnaby. "Risk Analysis of Tillage Alternatives with Government Programs." *Amer. J. Agr. Econ*. 72(1990):172-91.

Wu, J., and B.A. Babcock. "Metamodeling Potential Nitrate Water Pollution in the Central United States." *J. Environ. Qual*. 28(1999):1916-28.

Wu, J., and B.A. Babcock. "The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications." *Amer. J. Agr. Econ.* 80(1998):494-511.

Wu, J., and K. Segerson. "The Impact of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin." *Amer. J. Agr. Econ.* 77(1995):1033-47.