NÚMERO 369

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Measuring the Effects of Working-Land Conservation Programs on Adoption of Soil-Erosion Reducing Practices and Permanent Vegetative Cover

NOVIEMBRE 2006

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Acknowledgments

The author wants to thank Erik Lichtenberg for numerous, extensive and helpful suggestions, Marc Nerlove for his help with the MCEM estimation, and Richard Just for helpful comments to an early draft of this article.

Abstract

We use Maryland farm-level data to study the overall effect of voluntary conservation programs on permanent vegetative cover and the level of adoption of three soil-erosion reducing practices. In order to control for self-selectivity in participation we use a multivariate switching regression model where censored response equations correspond to the levels of adoption of the different practices under analysis. Full information maximum likelihood estimation is made feasible by a Monte Carlo Expectation Maximization algorithm. We find that participation increases the levels of adoption of the three erosion-reducing practices but it reduces permanent vegetative cover. Additionally, the magnitudes of program effects change with farm size; reduction in vegetative cover is more intense among smaller participant farms, while the greatest increase in adoption of minimum or no tillage is observed on large farms.

Resumen

Este artículo usa información de granjas en Maryland para estudiar el efecto de participar en programas voluntarios de conservación sobre la cobertura vegetal permanente y sobre el nivel de adopción de tres prácticas para reducir la erosión del suelo. Un modelo multivariado de regresiones "switching" es empleado para controlar por auto selección en la decisión de participar. Los niveles de adopción de las distintas prácticas son modelados mediante variables con respuestas censuradas. El modelo es estimado mediante máxima verosimilitud usando un algoritmo "Monte Carlo Expectation Maximization". Los resultados indican que la participación en estos programas aumenta los niveles de adopción de prácticas que controlan erosión pero también reduce la cobertura vegetal permanente. La magnitud de los efectos cambia con el tamaño de las granjas. La reducción de la cobertura vegetal es más intensa entre las granjas participantes más pequeñas, mientras que el impacto más fuerte sobre la adopción de mínima y cero labranza es observado entre las granjas más grandes.

Introduction

We use Maryland farm-level data to study the overall effect of voluntary conservation programs on permanent vegetative cover and the level of adoption of three soil-erosion reducing practices. In order to control for self-selectivity in participation we use a multivariate switching regression model where censored response equations correspond to the levels of adoption of the different practices under analysis. Full information maximum likelihood estimation is made feasible by a Monte Carlo Expectation Maximization (MCEM) algorithm. We found that participation increases the levels of adoption of the three erosion-reducing practices but it reduces permanent vegetative cover. Additionally, the magnitudes of program effects change with farm size; reduction in vegetative cover is more intense among smaller participant farms, while the greatest increase in adoption of minimum or no tillage is observed on large farms.

Key Words: Green payments, conservation cost sharing, MCEM

In the last twenty years, US farm policies have increased progressively the support for the conservation of farmland natural resources and the reduction of pollution from agricultural activities. A prominent example is the 2002 Farm-Bill authorization of a fivefold rise in the budget of the Environmental Quality Incentive Program (EQIP) and the creation of the Conservation Security Program (CSP); two programs that cost share the implementation of Best Management Practices (BMP) on working land.

As the budget for green payments increases, concerns about unintended effects that may be hampering program efficiency have been raised. One of these concerns is about the impact that adoption of land-quality improving practices may have on permanent vegetative cover. Many BMP eligible for cost sharing are erosion-reducing practices (e.g. no tillage, contour farming, strip cropping, and grade stabilization). Practices of this sort are also land quality augmenting since by preventing soil runoff they reduce the impact of land quality (e.g. land steepness) on farming activities. Theoretical analyses by Lichtenberg (2004) and Malik and Shoemaker (1993) suggest that adoption of land quality augmenting practices may expand cropping on marginal land and thus reduce vegetative cover. Cropping expansion would be a consequence of the higher profitability that conservation practices present on erodible land as compared with traditional cropping techniques.

If cropping expansion on marginal land does happen as result of program actions, then program efficiency can be impaired in more than one way due to the multi-objective nature of conservation programs. Marginal land is more susceptible to soil and nutrient runoff and thus water quality of nearby water bodies may be impaired. Additionally, the reduction of permanent vegetative cover reduces wildlife habitat. Loss of efficiency in EQIP has been documented by Cattaneo (2003), who suggests that limited enforcing capabilities incentive farmers to include in their applications a selection of BMP that maximize the probability to be awarded; yet, after cost sharing is provided, farmers implement only those practices in the contract that provides on-farm benefits.

This article uses farm level data from Maryland to analyze empirically the overall effect of cost-sharing payments on adoption of erosion-reducing BMP and acreage cropped. Although Maryland accounts for a small share of US agriculture, it is a suitable place to carry out such a study due to the state efforts to reduce agricultural pollution coming into the Chesapeake Bay. Actually, since its creation in 1982 the Maryland Agriculture Cost Sharing Program (MACS), a state funded program, has provided substantially more cost-share money to local farmers than federal programs such as EQIP (Bastos and Lichtenberg, 2001). We use a multivariate switching regression model and a MCEM formulation to estimate the joint effect of cost sharing on adoption of three BMP and vegetative cover. Our results indicate that the overall impact of cost sharing on BMP adoption and cropping expansion is both positive and substantial. The program impact on permanent vegetative cover, on the other hand, is also significant but negative. Furthermore, program impacts depend on farm size, with the reduction of vegetative cover being proportionally larger on smaller participant farms.

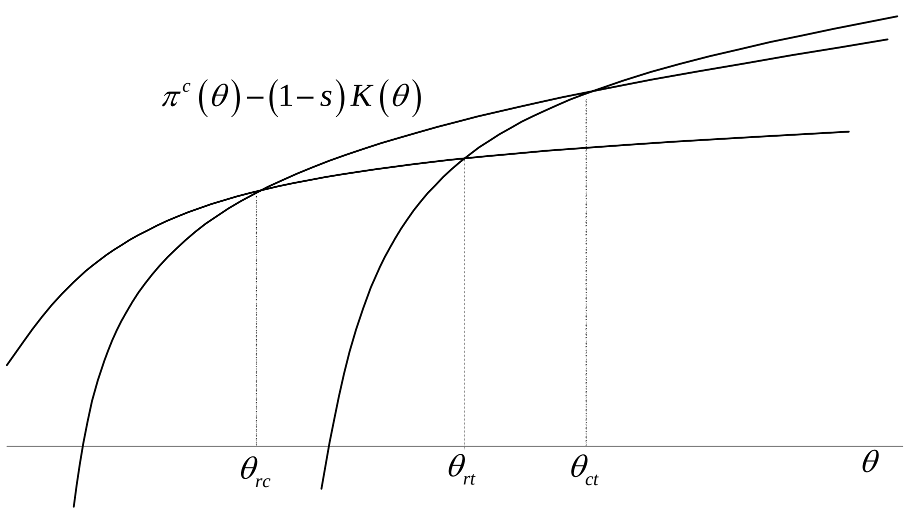
1. Theoretical framework

Next, we present the basics of the theory in Lichtenberg (2004) and Malik and Shoemaker (1993) only to introduce some concepts necessary for later discussion. Assume the landscape of any farm can be divided into plots of equal size, each of quality $\theta \in [0,1]$. Let $F(\theta)$ be the amount of land with quality no greater than θ, $F(0)=0$ and $F(1)=L$, where L is the farm size. Thus, $F(\theta)$ is the cumulative distribution of land quality. Let $f(\theta)$ be the corresponding density function. Assume farmers can allocate land to two uses only, intensive crop production and a residual use like annual or perennial pastures, hayland and/or wildlife habitat. Intensive crop production can be carried out by using either traditional cropping or by adopting an environmentally friendly practice. The innovation requires a start-up investment I (which may include machinery, building soil protection structures, and learning costs), and it has fixed production costs per acre

$K(\theta)$, which depend on land quality only and it is decreasing on it. Cropping under traditional techniques yields a net profit of $\pi^t(\theta)$ per acre, profit (before fixed and start up costs) from using the conservation practice is $\pi^c(\theta)$ per acre, while net profit per acre from the residual use is $\pi^r(\theta)$. In the context of this article, land quality θ is land steepness.

Assume that farmers are risk neutral, net profit functions $\pi^t(\theta)$, $\pi^r(\theta)$, and $\pi^c(\theta)-K(\theta)$ are quasiconcave on θ, and there exist unique $0 \le \theta_{rc} < \theta_{ct}$ such that $\pi^r(\theta_{rc}) = \pi^c(\theta_{rc}) - K(\theta_{rc})$ and $\pi^c(\theta_{ct}) - K(\theta_{ct}) = \pi^t(\theta_{ct})$. Finally, assume there is a program that cost shares a proportion $s \ge 0$ of start up and fixed cost of conservation practices. Assuming the innovation is adopted, the problem can be represented graphically as in Figure 1.

Figure 1. Optimal allocation of practices according to land quality when adoption of the conservation practice is profitable.



Mathematically, adoption takes place if the with-practice profit $\max_{\theta_{re},\theta_{et}} \left\{ \int_0^{\theta_{re}} \pi^r(\theta) f(\theta) d\theta + \int_{\theta_{re}}^{\theta_{et}} \left[\pi^e(\theta) - (1-s) K(\theta) \right] f(\theta) d\theta - (1-s)\tilde{I} + \int_{\theta_{et}}^{1} \pi^t(\theta) f(\theta) d\theta \right\}$ exceeds the without-practice profit $\max_{\theta_{rt}} \left\{ \int_0^{\theta_{rt}} \pi^r(\theta) f(\theta) d\theta + \int_{\theta_{rt}}^{1} \pi^t(\theta) f(\theta) d\theta \right\}$ where θ_{rt} is the land quality over which cropping is more profitable than the residual use in absence of the innovation, and $\tilde{I}$ is the annualized investment required for adoption. Rearranging terms, adoption happens if

$$\int_{\theta_{re}^*}^{\theta_{rt}^*}\left[\pi^e(\theta)-(1-s)K(\theta)-\pi^r(\theta)\right]f(\theta)d\theta+\int_{\theta_{rt}^*}^{\theta_{et}^*}\left[\pi^e(\theta)-(1-s)K(\theta)-\pi^t(\theta)\right]f(\theta)d\theta>(1-s)Y$$

where "*" indicates optimal choices. In words, the practice is adopted only if extra gains from the land on which the new practice replaces old ones exceed the start up investment. It is clear from above expression that cost sharing increases the gains and reduces the start up costs, all of which increase the probability of adoption. Additionally, if the innovation has been adopted, the envelope theorem implies

$$\frac{\partial\theta_{rc}^*}{\partial s}=\frac{K\left(\theta_{rc}^*\right)}{\pi^{'r}\left(\theta_{rc}^*\right)-\left[\pi^{'e}\left(\theta_{rc}^*\right)-(1-s)K^{'}\left(\theta_{rc}^*\right)\right]}<0 \qquad \frac{\partial\theta_{ct}^*}{\partial s}=\frac{K\left(\theta_{ct}^*\right)}{\pi^{'t}\left(\theta_{ct}^*\right)-\left[\pi^{'c}\left(\theta_{ct}^*\right)-(1-s)K^{'}\left(\theta_{ct}^*\right)\right]}>0$$

Thus, cost sharing (i) reduces the lowest quality of land on which cropping is practiced, i.e. it expands cropping on marginal land previously unprofitable to crop; and (ii) it expands the use of the conservation practice on land of higher quality by substituting traditional cropping techniques. Next sections present an empirical model and an estimation procedure to the first of these effects.

2. Data

Data used in the econometric estimation come from the 1998 University of Maryland BMP/Cost Share Survey. The Maryland Agricultural Statistics Service (MASS) conducted the survey. Stratified random sampling was used to ensure a sufficient number of responses from commercial operations, especially larger ones. Samples were drawn from the MASS master list of farmers and MASS provided expansion factors for deriving population estimates. The survey was administered using a computer assisted telephone survey instrument. The data set gathers information from 487 farms including farm operator characteristics, land ownership, crops planted in the last twelve months (corn, soybeans, small grains, vegetables, and tobacco), hayland and pasture acreage, livestock numbers, farm finance, farm topography, BMP used in the farm, acreage served by each practice, practices being cost shared, years cost sharing was received, and type of and distance to the closest water body. Among several others, the BMP considered in the survey and relevant for this study are contour farming/strip cropping, cover crops, minimum or no tillage, permanent vegetative cover, pasture and hayland planting, and wildlife habitat. All of them eligible for cost sharing and, as discussed below, running cropping operations. Information from 355 farms (out of 487) that provided full answers was considered for the analysis. Tests to check for systematic attrition resulted non-significant. Thus, non-respondents dropped from the analysis seem to have occurred randomly and no adjustment to the expansion factors was needed.

This article assesses the impact of cost-share payments on the adoption of three soil-erosion reducing practices: contour/strip cropping, cover crops, and minimum/no tillage. A brief description of these practices follows.

- *Contour/strip cropping*. Preparing land, planting, and cultivating along the contour lines to reduce erosion and control water flow. Strip cropping alternates contour strips of sod and row crops to slow runoff and filter out eroded soil.
- *Cover crops.* A cover crop is any crop grown to provide soil cover, regardless of whether it is later incorporated as green manure. Cover crops are grown primarily to prevent soil erosion by wind and water.
- *Minimum and or no tillage*. Soil is covered by crop residue after planting to reduce erosion by water or wind. In no tillage systems, planting is the only soil disturbing operation. Minimum tillage allows some tillage to solve problems related to weeds, excessive moisture or heavy clay soil conditions.

None of the three practices had been implemented in more than 45% of Maryland farms by the time of the survey, and fewer than 10% of the farms that had implemented them had received funding. Program participation may seem low in Maryland, but it is probably higher than in many other states since, as discussed before, several state programs have been established in order to reduce agricultural pollution coming into the Chesapeake Bay waters.

3. The effect of cost sharing on acreage cropped

The estimation of cost sharing effects on expansion of cropland needs further elaboration. In Maryland, crops can be planted using either single or double cropping. Data available do not allow distinguishing how much acreage has been single or double cropped, but how much acreage has been planted to each crop in the last twelve months. Thus, the sum of acres allocated to all the crops would overestimate the share of the farm used for cropping. To overcome this limitation we proceed in the way described below.

Let A be total acreage operated, A_s the single-cropped acreage, A_d the acreage used for double cropping, A_v the acreage under vegetative cover (hayland, grassland and wildlife habitat), and A_o the acreage under other uses (e.g. machinery storage, livestock facilities, housing, roads). Thus, $A = A_s + A_d + A_v + A_o = A_{cr} + A_v + A_o$ and a cropping expansion effect is a change in $A_{cr} = A_s + A_d$. Consider now the following assumptions:

Assumption 1: *The effect of cost sharing funding on acreage used in machinery storage, livestock facilities, housing or roads, ΔA_0, is negligible*. Since cost sharing is provided as a reimbursement of costs actually incurred, it is unlikely a farmer use these funds in housing or roads. On the other hand, the construction of machinery storage is a possible indirect effect of cost sharing the adoption of minimum tillage. However, this effect (if existing) is likely to be small if compared with the direct effect ΔA_{cr} (we expect that a farmer willing to invest in machinery and storage facilities will use that machinery).

Assumption 2: *Total acreage operated, A, does not change as consequence of cost-sharing funding*. This might be a restrictive assumption, mainly because adoption of some practices might incentive farmers to rent land in to reduce per acre financial and maintenance cost of machinery. Evaluating such an effect, however, requires longitudinal data, which we do not have. We expect to tackle this issue in future research.

If the two assumptions hold, then the change in A_{cr}/A is

$$\frac{\Delta A_{cr}}{A} = \frac{\Delta A}{A} - \frac{\Delta A_v}{A} - \frac{\Delta A_o}{A} \cong -\frac{\Delta A_v}{A} \quad \textbf{(1)}$$

Thus, we can use the negative of the change in the share of land under permanent vegetative cover to estimate the change in the share of land used for planting crops. In this article we use the sum of acreage allocated to hayland, pasture, and wildlife habitat to calculate the share of the farm allocated to permanent vegetative cover.

4. The econometric model and estimation strategy

Conservation and production decisions are interrelated and our econometric model must acknowledge this interdependency. Additionally, self-selection is a definite issue when modeling voluntary program participation since applying for cost sharing is more likely among farmers finding both practice implementation and program participation profitable. Cost share awarding, on the other hand, is influenced by the preferences of programs' administrative bodies. Thus, a consistent estimation of program effects requires modeling participation, conservation, and production decisions jointly.

4.1 The model

Our econometric approach must allow for the construction of the counterfactual in order to estimate the effect of the treatment (cost-share program) on the treated. Therefore, the following switching regression approach, which is a multivariate generalization of Maddala's (1983) model, is proposed:

$$
\begin{array}{lll}
 & y_{1i}^{*} = X_{1i}\beta_1 + \varepsilon_{1i} & \text{Cost sharing (selection) equation} \\
y_{1i}=0 \; [& \qquad] \; y_{1i}=1 & \\
y_{2i}^{*0} = X_{2i}\beta_2^0 + \eta_{2i}^0 & y_{2i}^{*1} = X_{2i}\beta_2^1 + \eta_{2i}^1 & \text{Vegetative cover equation} \\
y_{3i}^{*0} = X_{3i}\beta_3^0 + \eta_{3i}^0 & y_{3i}^{*1} = X_{3i}\beta_3^1 + \eta_{3i}^1 & \text{Contour/strip cropping equation} \\
y_{4i}^{*0} = X_{4i}\beta_4^0 + \eta_{4i}^0 & y_{4i}^{*1} = X_{4i}\beta_4^1 + \eta_{4i}^1 & \text{Cover crop equation} \\
y_{5i}^{*0} = X_{5i}\beta_5^0 + \eta_{5i}^0 & y_{5i}^{*1} = X_{5i}\beta_5^1 + \eta_{5i}^1 & \text{Minimum/no tillage equation}
\end{array}
\qquad \textbf{(2)}
$$

where the left-hand side variables are defined as it follows:

y_{1i}^{*} is a latent variable giving the propensity of farm i to apply for and be awarded cost sharing. Only a binary variable, y_{1i}, is observed, taking the value one if cost sharing has been awarded in the period 1983-98 for the implementation of at least one of the practices being analyzed and/or for planting vegetative cover or protecting wildlife habitat and zero if not.

Variables y_{2i}^{*}, y_{3i}^{*}, y_{4i}^{*} and y_{5i}^{*} are the levels at which vegetative cover (including pastures, hayland and wildlife habitat), contour/strip cropping, cover crops, and minimum/no tillage are used in the farm, respectively. Their observed counterparts y_{2i}, y_{3i}, y_{4i}, and y_{5i}, are estimated by the ratio between the acreage served by the respective practice and total acreage cropped. Thus, they are censored from below at zero and from above at one. Summarizing:

$$
y_{ji} = \begin{cases} 0 & \text{if} \quad y_{ji}^{*} \le 0 \\ y_{ji}^{*} & \text{if} \quad 0 < y_{ji}^{*} < 1 \\ 1 & \text{if} \quad y_{ji}^{*} \ge 1 \end{cases} \qquad j = 2,3,4,5
$$

Vectors X_{ji} $j = 1,\ldots,5$ in (2) represent exogenous explanatory variables. Coefficients β_j^0 y β_j^1 are parameter vectors related to exogenous regressors for regimes $y_{1i} = 0$ and $y_{1i} = 1$, respectively. Vectors $\left(\varepsilon_{1i} \quad \eta_{2i}^0 \quad \eta_{3i}^0 \quad \eta_{4i}^0 \quad \eta_{5i}^0\right)$ and $\left(\varepsilon_{1i} \quad \eta_{2i}^1 \quad \eta_{3i}^1 \quad \eta_{4i}^1 \quad \eta_{5i}^1\right)$ are normally distributed disturbances with zero means and 6x6 covariance matrices. Variance of ε_{1i} is set equal to one according to the usual normalization required to identify the parameters in equations that involve dichotomous dependent variables.

It could be argued that the size of the conservation project influences both the decision about whether to apply or not for cost sharing and the decision to grant it. This suggests the inclusion of the left-hand side variables from the adoption equations as explanatory variables in the selection equation. Solving a structural model like that, however, is not necessary for the purposes of this article. Solving the reduced form as in (2) is sufficient to estimate the program effects.

Controlling for self-selection in the bundle of practices to be adopted is frequent in applied literature on technology adoption since farmers are more likely to adopt those practices that they find more profitable (Fuglie and Bosch, 1995; Khanna, 2001). The problem in this article, however, is somewhat different as the purpose of cost sharing is precisely to alter practice relative profitability. Hence, the questions of interest are: (1) do changes in profitability happen as result of program participation? and, if they do, (2) what are their effects on adoption of BMP? The equation system in (2) is suitable for quantifying those effects. The first equation models a dichotomous indicator for program participation, while the remaining equations model censored response variables for levels of specific practice adoption conditional on whether the farm participates in a program or not.

Our model assume that operation type is not influenced by program participation since working-land programs reimburse implementation costs only for practices that make current operations less polluting. On the other hand, the practices under study are compatible with crop production only (including hayland planting). As our selection of practices is exogenous, we circumvent this source of inconsistency by restricting the analysis to the subsample of farms running cropping operations. Additionally, in order to rule out hobby farmers, we consider farms with cropping operations larger than five acres (about 92% of the total sample).

It is important to remark that the binary Cost-share variable is defined as 1 if the farmer has received cost share in the period 1983-1998 for implementing at least one of the three practices being under analysis and/or for protecting permanent vegetative cover or wildlife habitat. Year 1983 was the year MACS started to work and it is the earliest year cost-share awarding was reported in the sample, while the data was collected by the end of 1998. The survey did not discriminate according to cost-sharing provider, i.e. a “yes” answer to the cost-share awarding questions means the farmer is (or was) a participant in any of the conservation programs operating in the area. Hence, the program effect estimates presented below must be interpreted as the overall impact of participating in a cost-share program during some time interval of the period 1983-1998 as compared against farmers that have never participated in such programs. We mean by overall impact not only the direct effect of the program on the level of adoption of practices for which money has being granted, but also spillover effects of program money on the adoption level of practices not being directly cost shared.

Table 1. Dependent and exogenous explanatory variables

Variable Name	Description	Mean	Standard Deviation
Cost share	Binary variable indicating whether the farmer has received cost sharing for implementation of at least one of the four practices under study in the last fifteen years (yes=1).	0.144	0.351
Vegetative cover	Proportion of land under hayland, pasture or wildlife habitat to total acreage operated.	0.323	0.302
Contour/strip cropping	Proportion of land cropped using contour and/or strip cropping to total acreage cropped.	0.174	0.315
Cover crops	Proportion of land planted to cover crops to total acreage cropped.	0.112	0.201
Minimum/no tillage	Proportion of land cropped using minimum or no tillage techniques to total acreage cropped.	0.229	0.317
CSAge [1]	Age of the farmer in the most recent year cost share funding was received since 1983	58.331	12.362
Age [2,3,4,5]	Current farmer age	58.773	11.950
College [1,2,3,4,5]	Farmer has college education or higher or has attended to technical school (yes = 1)	0.271	0.445
Slope [1,2,3,4,5]	Proportion of total acreage operated with slope greater than 2%.	0.402	0.392
Rented [1,2,3,4,5]	Proportion of total land operated that is rented in	0.163	0.300
Land [1,2,3,4,5]	Total acreage operated (10^3 acres)	212.142	296.291
Distance [1]	Distance to the nearest water body (miles)	0.836	3.297
NC [1,2,3,4,5]	The farm is in West/Central Maryland [a]	0.574	0.495
SC	The farm is in Southern Maryland [b]	0.160	0.367
UES [1,2,3,4,5]	The farm is in the Upper Eastern Shore [c]	0.128	0.334
LES [1,2,3,4,5]	The farm is in the Lower Eastern Shore [d]	0.138	0.345

[1] Included as a regressor in the selection equation; [2] included as a regressor in the vegetative cover equation; [3] included as a regressor in the contour/strip cropping equation; [4] included as a regressor in the cover crop equation; [5] included as a regressor in the minimum/no tillage equation.

[a] NC includes Baltimore, Carrol, Frederick, Harford, Howard, Montgomery, Washington, Allegany, and Garret counties.

[b] SM includes Anne Arundel, Calvert, Charles, Prince Georges, and St. Marys counties.

[c] UES includes Caroline, Cecil, Kent, Queen Annes, and Talbot counties.

[d] LES includes Dorchester, Somerset, Wicomico, and Worcester counties Sample size = 355.

Table 1 provides descriptive statistics for the regressors X_{ji} and it indicates which regressors were considered in each equation. Farmer characteristics like AGE (both current and at the last year of receiving cost-share funding) and EDUCATION were considered in the analysis. Farmer age is used as a measure of farmer's time horizon, while education is used to proxy off-farm income and farmer perception about private and social benefits from the use of conservation practices.

Farm topography is considered by introducing the variable SLOPE, which gives the percentage of land operated with a slope higher than 2%. We control for tenancy by incorporating a variable giving the percentage of land operated that is RENTED in. Renters are widely believed to have less incentive to invest in conservation since long run returns accrue to the property owner, not the tenant.

Total acreage (LAND) operated was included to control for the effects of farm size. Large farms may have more incentives to apply for cost sharing since they are likely to have a more diverse topography. Program administrators, on the other hand, may target preferentially those farms that are likely to be large pollution sources.

A continuous variable giving the DISTANCE to the closest water body (stream, lake, pond, wetland, or the Chesapeake Bay) was included in the selection equation. Since protection of water quality in the Bay and its tributaries is the expressed top priority of Maryland's conservation programs, it is expected that proximity to water bodies increases the likelihood to receive funding. Finally, we included four dummy variables indicating farm location: Southern Maryland (SC), Upper Eastern Shore (UES), Lower Eastern Shore (LES), and West-Central Maryland (NC). We expect to capture with these dummies the effects of differences in the mix of agricultural activities and the importance of agriculture in the local economy. The Upper Shore specializes in corn and soybean production, the Lower Shore in poultry. West-Central Maryland specializes in dairy.

4.2 Estimating the effects of cost sharing

The effect of cost sharing payments on the adoption level of the different practices is estimated by the change in the share of land served by each practice. Following Maddala (1983), the program effect is estimated from farmers who have received cost sharing. Let the current observed share of land covered by practice j in the awarded farm i be y_{ji} and y_{ji}^0 its observed counterpart had the farmer chosen not to participate. The cost sharing effect is then:

$$\begin{aligned}\Delta S_{ji} &= y_{ji} - E\left[y_{ji}^0 \mid y_{1i}=1\right] \\ &= y_{ji} - \Pr\left[0<y_{ji}^0<1 \mid y_{1i}=1\right]E\left[y_{ji}^0 \mid 0<y_{ji}^0<1, y_{1i}=1\right] - \Pr\left[y_{ji}^0=1 \mid y_{1i}=1\right]\end{aligned} \quad \textbf{(3)}$$

The average of ΔS_{ji} ($j = 3,4,5$) on all participants gives the average impact of the program on a participant farm. Expressions to calculate the terms on the right-hand side of (3) are given in Appendix 1. Given the observed variable y_{ji} is the proportion of cropped acreage on which practice j is used to total acreage cropped, ΔS_{ji} must be interpreted as the change in that proportion as result of program participation.

To estimate the effect of cost-share funding on the share of land under vegetative cover we can use $j = 2$ in expression (3). Sample estimates for all effects were calculated by the mean of the individual effects. Standard errors were obtained by the delta method.

4.3 Econometric estimation by a MCEM algorithm

Due to its asymptotic properties, a full information maximum likelihood approach is preferred to a 2-stage estimation of an equation system such as (2). Estimation by traditional numerical techniques, however, is not feasible due to the unobserved information implicit in the latent dependent variables, which introduces 5-dimensional integrals in the likelihood function. In order to circumvent this issue, we implement a MCEM algorithm.

For a flavor of how the MCEM method works, consider the many-to-one mapping $z \in Z \to y = y(z) \in Y$. In words, z is only known to lie in $Z(y)$, the subset of Z determined by the equation $y = y(z)$, where $\boldsymbol{y}$ is the observed data and $\boldsymbol{z}$ is the (complete) unobserved information. Thus, the log-likelihood of the observed information is

$$\mathrm{l}\left(\theta \mid \boldsymbol{y}\right) = \ln L\left(\theta \mid \boldsymbol{y}\right) = \ln \int_{Z(y)} L\left(\theta \mid \boldsymbol{z}\right) d\boldsymbol{z} \qquad \textbf{(4)}$$

Instead of solving (4) directly, the EM algorithm focuses on the complete-information log-likelihood $\ell^c\left(\theta \mid \boldsymbol{z}\right)$ and maximizes $\boldsymbol{E}\left[\mathrm{l}^{\boldsymbol{c}}\left(\theta \mid \boldsymbol{z}\right) \mid \boldsymbol{y}\right]$ by executing two steps iteratively (Dempster, Laird, and Rubin, 1977). The first one is the so-called Expectation step (E-step), which computes $Q\left(\theta \mid \theta^{(m)}, \boldsymbol{y}\right) = E\left[\mathrm{l}^c\left(\theta \mid \boldsymbol{z}\right) \mid y\right]$ at iteration *m*+1, where $\boldsymbol{E}\left[\mathrm{l}^{\boldsymbol{c}}\left(\theta \mid \boldsymbol{z}\right) \mid \boldsymbol{y}\right]$ is the expectation of the complete-information log-likelihood conditional on the observed information and provided that the conditional density $\boldsymbol{f}\left(\boldsymbol{z} \mid \boldsymbol{y}, \theta^{(\boldsymbol{m})}\right)$ is known. The E-step is followed by the Maximization step (M-step), which maximizes $Q\left(\theta \mid \theta^{(m)}, \boldsymbol{y}\right)$ to find $\theta^{(m+1)}$. The procedure is then repeated until convergence is attained.

The Monte Carlo version of the EM algorithm (Wei and Tanner, 1990) avoids troublesome computations in the E-step by imputing the unobserved information by Gibbs sampling conditional on what is observed and distribution assumptions (Casella and George, 1992). In this approach, the

term $Q\left(\theta \mid \theta^{(m)}, \boldsymbol{y}\right)$ is approximated by the mean $\frac{1}{K}\sum_{k=1}^{K} Q\left(\theta, \boldsymbol{z}^{(k)} \mid \boldsymbol{y}\right)$, where the $\boldsymbol{z}^{(k)}$ are random draws from $f\left(\boldsymbol{z} \mid \theta^{(m)}, \boldsymbol{y}\right)$. The implementation of a MCEM algorithm to estimate the equation system in (2) is presented in Appendix 2.
Finally, we extended the formulation of Harley (1976) to test for heteroskedasticity of the type $\sigma_i^2 = \sigma_0^2 \exp(Z_i \alpha)$ in all the equations of our model simultaneously. Variables in the vector Z_i included LAND and the location dummies (UES, LES and NC) as proxies for spatial heterogeneity and operation type respectively. A Wald test did not reject the homoskedasticity hypothesis ($\alpha = 0$). Estimation results for the parameters in the model are provided in Appendix 3.

Results discussion

Differences in the expected shares of land served by different practices as result of cost-share funding are presented in Table 2. Results are displayed for the complete cost-shared sample and according to farm size as well. Farm sizes used to present the results, however, do not necessarily represent the actual distribution of Maryland farms but the distribution of cost-shared farms in the sample, which sizes range from 48 to 3,700 acres. Accordingly, we label as Small those farms not larger than 200 acres, as Medium those farms above 200 but not larger than 500 acres, and as Large those farms larger than 500 acres.

Table 2. Estimated effects of cost-share payments on adoption of conservation practices

Practice	Farm size	Change in the share of land served	
		Estimate[d]	As. std error[c]
Vegetative cover	Small	-0.2995 [a] A	0.0240
	Medium	-0.2092 [a] B	0.0217
	Large	-0.1206 [a] B	0.0333
	Sample average	-0.2231 [a]	0.0209
Contour/Strip cropping	Small	0.2039 [a] A	0.0194
	Medium	0.1484 [a] AB	0.0103
	Large	0.1203 [a] B	0.0191
	Sample average	0.1619 [a]	0.0128
Cover crops	Small	0.1249 [a] A	0.0050
	Medium	0.1293 [a] A	0.0060
	Large	0.1820 [a] A	0.0116
	Sample average	0.1376 [a]	0.0057
Minimum/no tillage	Small	0.3167 [a] A	0.0002
	Medium	0.1508 [a] B	0.0021
	Large	0.4418 [a] C	0.0107
	Sample average	0.2607 [a]	0.0027

[a] Significant at 1% significance.
[b] significant at 5% significance.
[c] Asymptotic standard error estimated by the delta method.
[d] For each practice box, different capital letters imply the estimates are different at 5% of significance.

5.1 Effect of cost-sharing payments on adoption of conservation practices and permanent vegetative cover

In accordance with results from the theoretical section, 1983-98 cost-sharing payments have expanded the use of contour/strip cropping, cover crops, and minimum/no tillage. Furthermore, conservation payments have increased the coverage of these three practices at all levels of farm size. However, cost sharing has had a negative impact on the share of land under permanent vegetative cover. The share under hayland, pastures and/or wildlife habitat has reduced in an average of 22.3 percentage points (pp hereafter); while on Small, Medium and Large farms the reductions achieve 30.0 pp, 20.9 pp, and 12.1 pp[1], respectively. The empirical results confirm hypotheses proposed by Malik and Shoemaker (1993) and Lichtenberg (2004), namely: cost sharing (i) increases the use of land quality augmenting conservation practices and (ii)

[1] Large participant farms in the sample average 11% of their operated land allocated to permanent pastures, hayland and/or wildlife habitat; our results indicate this percentage had been about 23% had these farms not participated in the program. Results for Small and Medium farms must be interpreted in an analogous way.

promotes cropping on lower quality land resulting in reduced vegetative cover.

Results also suggest that cost sharing may have a positive effect on the use of practices presenting private incentives, but a negative effect on practices having positive off-farm spillovers[2] (such as the use of permanent vegetative cover). Thus, practices that supply off-farm benefits may not be implemented or, if existing on the farm, they could be "substituted" by practices that provide on-farm benefits. Cattaneo (2003) has reported that one or more practices were not implemented in 17% of early EQIP contracts. Practices with the highest rates of withdrawal include brush management, range planting, filter strips, forest site preparation, critical area planting, waste treatment lagoon, and prescribed burning; all of them providers of important off-farm benefits. Vukina, Levy, and Marra (2003), who use data from CRP auctions to study farmers' attitudes towards the environment, shed additional light about this issue. By the analysis of the way in which farmers construct their bids, the authors conclude that farmers "…value those environmental benefits that affect the productivity of their land directly but do not value those benefits that resemble public goods".

We implemented several Wald tests to compare the impacts of program participation on farms of different size, i.e. we compare Small vs. Medium, Small vs. Large and Medium vs. Large for all the practices under analysis. We detect no influence of farm size on the impact that the program has on the use of cover crops, which averages 13.8 pp and it is statistically similar on the three size categories we consider. Regarding to the level of adoption of contour and strip cropping, Small and Medium farms show positive impacts of similar magnitude (20.4 and 14.8 pp, respectively), while Large farms show an effect of 12.0 pp[3], which is statistically smaller to the effect on Small farms but similar to the effect observed on Medium farms. Comparisons for the impacts on vegetative cover and minimum/no tillage are presented below in the context of cropping expansion.

5.2 Effects of cost-sharing payments on cropping

From equation (1), we know that the negative of the effect of cost sharing on permanent vegetative cover provides us with an estimate of the program effect on cropping. Thus, according to Table 2, the average effect of cost sharing on acreage cropped is positive and close to 22.3 pp. The magnitude of cost sharing impact, however, depends on farm size. The strongest effect is

[2] Vegetative cover provides scenery and wildlife habitat. Additionally, pasture and permanent vegetative cover are biodiversity reservoirs, they sequester carbon from the atmosphere and filter pollutans before they reach surface or underground water.

[3] Large participant farms in the sample average 18% of their cropped acreage as cultivated using contour/strip cropping; our results indicate this percentage had been 3% had these farms not participated in the program. Results for Small and Medium farms and for the rest of the practices (except permanent vegetative cover) must be interpreted in an analogous way.

observed on Small farms, where the land share under cropping is about 30.0 pp greater among program participants. The expansion effect reduces to 20.9 and 12.1 pp on Medium and Large farms respectively, all of them statistically significant. The reduction of this effect with size probably obeys to the fact that smaller farms are more land-quality constrained than large farms. Because of their size, medium and large farms have a wider distribution of land quality, which means they have a greater likelihood of including tracts of land on which raising crops is profitable. Thus, all else equal, small farms are more likely to have crop operations proportionally smaller than observed on medium and large farms. Therefore, adoption of land-quality enhancing practices should have a proportionately larger expansion effect on smaller farms.

The impact of the program on the level of adoption of minimum/no tillage also shows dependency on farm size. The greatest impact is observed on Large farms, which use minimum/no tillage on a proportion of the cropped acreage that is 44.2 pp greater than non-participant farms. This result is not surprising as large farms are more likely to be labor and time constrained and minimum and no tillage provides significant savings in time and labor. In accordance with our previous findings, estimations from the ERS (2005) indicate the existence of economies of scale for practices such as no tillage, pasture and hay planting, and wildlife habitat management, but nor for cover crops. On the other hand, the relatively high impact on the adoption of minimum/no tillage on Small farms (31.7 pp) can be explained by the existence of land quality constraints as discussed above. Minimum and no tillage are land-quality enhancing and thus, they are more profitable than traditional techniques when cultivating marginal land.

Conclusions

We analyzed interactions between farmers' conservation and production decisions in a disaggregated multivariate framework. We showed that farms awarded cost share funding implement land-productivity improving practices on a greater share of land than farms that have not received cost sharing. This outcome indicates that cost-sharing programs can be successful in spreading the adoption of this type of BMP. Second, we showed evidence of an unintended effect of cost sharing payments: as farmers choose to implement preferentially those practices providing private gains, the expansion in cropping induced by cost sharing these practices may reduce the share of land covered by practices that provide off-farm benefits. The analysis indicates that expansion of cropping on marginal land predominates on small and medium participant farms.

Regarding to the "green" quality of working-land conservation programs, program administrators may need to consider more severe restrictions to cropping expansion and evaluate whether the adoption of some land-quality augmenting practices needs to be cost-shared at current reimbursement rates. From a conservationist point of view, results suggest that payment for practices providing off-farm benefits may need to be increased in order to make them comparable to the opportunity costs of allocating land to them.

Maryland, on the other hand, is a small state that contains a small proportion of US cropland and produces a small share of US agricultural output. Similar studies using data from larger and more agricultural states are necessary to confirm the scope of this study's findings.

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Appendix 1

$$\Pr\left[y_{ji}^{0}=1 \mid y_{1i}=1\right]=\frac{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{jj}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}{\Phi_{1}\left(X_{1i}\beta_{1}\right)}$$

$$\Pr\left[0<y_{ji}^{0}<1 \mid y_{1i}=1\right]=\frac{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)-\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}},-\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}{\Phi\left(X_{1i}\beta_{1}\right)}$$

where $\Phi_{d}(\cdot)$ is the *d*-dimensional normal standard cdf, $\rho_{\varepsilon_{1}\eta_{j}^{0}}$ is the correlation between ε_{j} and η_{j}^{0} and σ_{jj}^{0} is the variance of η_{j}^{0}, $j=2,3,4,5$.
Additionally, following the work of Rosenbaum (1961):

$$E\left[y_{ji}^{0} \mid 0<y_{ji}^{0}<1, y_{1i}=1\right]=X_{ji}\beta_{j}^{0}+\frac{\phi\left(\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}}\right)}{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)-\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}},-\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}\Phi\left(-\frac{X_{1i}\beta_{1}-\rho_{\varepsilon_{1}\eta_{j}^{0}}\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}}}{\left(1-\rho_{\varepsilon_{1}\eta_{j}^{0}}^{2}\right)^{1/2}}\right)+$$

$$\rho_{\varepsilon_{1}\eta_{j}^{0}}\frac{\phi\left(X_{1i}\beta_{1}\right)}{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)-\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}},-\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}\Phi\left(-\frac{\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}}-\rho_{\varepsilon_{1}\eta_{j}^{0}}X_{1i}\beta_{1}}{\left(1-\rho_{\varepsilon_{1}\eta_{j}^{0}}^{2}\right)^{1/2}}\right)-$$

$$\frac{\phi\left(\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}}\right)}{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)-\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}},-\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}\Phi\left(-\frac{X_{1i}\beta_{1}-\rho_{\varepsilon_{1}\eta_{j}^{0}}\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}}}{\left(1-\rho_{\varepsilon_{1}\eta_{j}^{0}}^{2}\right)^{1/2}}\right)-$$

$$\rho_{\varepsilon_{1}\eta_{j}^{0}}\frac{\phi\left(X_{1i}\beta_{1}\right)}{\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}}{\sigma_{j}^{0}},\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)-\Phi_{2}\left(X_{1i}\beta_{1},\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}},-\rho_{\varepsilon_{1}\eta_{j}^{0}}\right)}\Phi\left(-\frac{\dfrac{X_{ji}\beta_{j}^{0}-1}{\sigma_{j}^{0}}-\rho_{\varepsilon_{1}\eta_{j}^{0}}X_{1i}\beta_{1}}{\left(1-\rho_{\varepsilon_{1}\eta_{j}^{0}}^{2}\right)^{1/2}}\right)$$

Appendix 2

The complete information log-likelihood function for the equation system (2) is

$$\ell^c(\beta,\Omega_0,\Omega_1 \mid y) = -3N\ln(2\pi) - \frac{n_0}{2}\ln|\Omega_0| - \frac{n_1}{2}\ln|\Omega_1| - \frac{1}{2}\mathrm{tr}\left(\Omega_0^{-1}\sum_{y_{1i}=0}\varepsilon_i^0\varepsilon_i^{0'}\right) - \frac{1}{2}\mathrm{tr}\left(\Omega_1^{-1}\sum_{y_{1i}=1}\varepsilon_i^1\varepsilon_i^{1'}\right) \quad (5)$$

where $\beta = \begin{pmatrix}\beta_1 & \beta_2^0 & \cdots & \beta_5^0 & \beta_2^1 & \cdots & \beta_5^1\end{pmatrix}'$, $n_k\ (k=0,1)$ is the number of observations with $y_{1i}=k$, $\varepsilon_i^k = \begin{pmatrix}\varepsilon_{1i} & \eta_{2i}^k & \eta_{3i}^k & \eta_{4i}^k & \eta_{5i}^k\end{pmatrix}'$, Ω_k is the covariance matrix of ε_i^k.

E-Step

The expectation of expression (5), conditional on observed information and distribution assumptions, can be written as:

$$\ell^c(\beta,\Omega_0,\Omega_1 \mid y) = -\frac{5}{2}N\ln(2\pi) - \frac{n_0}{2}\ln|\Omega_0| - \frac{n_1}{2}\ln|\Omega_1| - \frac{1}{2}\mathrm{tr}\left(\Omega_0^{-1}\sum_{y_{1i}=0}E\left[\varepsilon_i^0\varepsilon_i^{0'}\right]\right) - \frac{1}{2}\mathrm{tr}\left(\Omega_1^{-1}\sum_{y_{1i}=1}E\left[\varepsilon_i^1\varepsilon_i^{1'}\right]\right)$$

The E-step at iteration $m+1$, requires the calculation of:

$$Q_i^k\left(\beta \mid \beta^{(m)},\Omega_k^{(m)},y\right) = E\left[\varepsilon_i^k\varepsilon_i^{k'} \mid \beta^{(m)},\Omega_k^{(m)},y\right] == \sigma_i^{2(k,m)} + \begin{pmatrix}\mu_{y_{1i}^*}^{(k,m)} - X_{i1}\beta_1 \\ \mu_{y_{2i}^*}^{(k,m)} - X_{i2}\beta_2^k \\ \mu_{y_{3i}^*}^{(k,m)} - X_{i3}\beta_3^k \\ \mu_{y_{4i}^*}^{(k,m)} - X_{i4}\beta_4^k \\ \mu_{y_{5i}^*}^{(k,m)} - X_{i5}\beta_5^k\end{pmatrix}\begin{pmatrix}\mu_{y_{1i}^*}^{(k,m)} - X_{i1}\beta_1 \\ \mu_{y_{2i}^*}^{(k,m)} - X_{i2}\beta_2^k \\ \mu_{y_{3i}^*}^{(k,m)} - X_{i3}\beta_3^k \\ \mu_{y_{4i}^*}^{(k,m)} - X_{i4}\beta_4^k \\ \mu_{y_{5i}^*}^{(k,m)} - X_{i5}\beta_5^k\end{pmatrix}'$$

where $\sigma_i^{2(k,m)} = \mathrm{Cov}\left(y_{1i}^{k*},\dots,y_{5i}^{k*} \mid \beta^{(m)},\Omega_k^{(m)},y\right)$ and $\mu_{y_{ji}^{k*}}^{(k,m)} = E\left[y_{ji}^{k*} \mid \beta^{(m)},\Omega_k^{(m)},y\right] \quad j=1,\dots,5$

M-Step

We split the M-step in two conditional maximizations (Meg and Rubin, 1993). The first one maximizes $\ell^c(\beta,\Omega_0,\Omega_1 \mid y)$ with respect to the elements in β conditional on $\beta^{(m)}$ and $\Omega_k^{(m)}$. The maximizer can be written as the generalized least square estimator

$$\beta^{(m+1)} = \left[\tilde{X}_d'\left(\tilde{\Omega}_0^{(m)}\otimes I^0 + \tilde{\Omega}_1^{(m)}\otimes I^1\right)\tilde{X}_d\right]^{-1}\tilde{X}_d'\left(\tilde{\Omega}_0^{(m)}\otimes I^0 + \tilde{\Omega}_1^{(m)}\otimes I^1\right)\mu_{y^*}^{(m)}$$

where I^k is a $N \times N$ diagonal matrix with $I_{ii}^k = 1$ if $y_{1i} = k$ and $I_{ii}^k = 0$ otherwise, and $\tilde{X}_d$ is a block diagonal matrix constructed in the following way:

$$\tilde{X}_d = \begin{bmatrix} X_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & X_2^0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X_5^0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X_2^1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X_5^1 \end{bmatrix}, \quad X_{ij}^k = 0 \ \forall i \text{ if } y_{1i} \neq k, \quad j = 2,\ldots 5,\ k = 0,1.$$

The column vector $\mu_{y^*}^{(m)} = \left(\mu_{y_1^*}^{(m)} \quad \mu_{y_2^*}^{(0,m)} \quad \cdots \quad \mu_{y_6^*}^{(1,m)} \quad \mu_{y_2^*}^{(0,m)} \quad \cdots \quad \mu_{y_6^*}^{(1,m)} \right)'$, where $\tilde{\mu}_{y_j^*}^{(k,m)} = \left(\mu_{y_{j1}^*}^{(k,m)} \quad \cdots \quad \mu_{y_{jN}^*}^{(k,m)} \right)'$, and $\mu_{y_{ij}^*}^{(k,m)} = 0$ if $y_{1i} \neq k$, and I_N is an identity matrix. Finally, the matrices $\tilde{\Omega}_k^{(m)}$ are:

$$\tilde{\Omega}_0^{(m)} = \begin{bmatrix} \tilde{\omega}_{11}^{(0,m)} & \tilde{\omega}_{12}^{(0,m)} & \cdots & \tilde{\omega}_{15}^{(0,m)} & 0 & \cdots & 0 \\ \tilde{\omega}_{12}^{(0,m)} & \tilde{\omega}_{22}^{(0,m)} & \cdots & \tilde{\omega}_{25}^{(0,m)} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \cdots & \vdots \\ \tilde{\omega}_{15}^{(0,m)} & \tilde{\sigma}_{25}^{(0,m)} & \cdots & \tilde{\omega}_{55}^{(0,m)} & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \end{bmatrix} \qquad \tilde{\Omega}_1^{(m)} = \begin{bmatrix} \tilde{\omega}_{11}^{(1,m)} & 0 & \cdots & 0 & \tilde{\omega}_{12}^{(1,m)} & \cdots & \tilde{\omega}_{15}^{(1,m)} \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ \tilde{\omega}_{12}^{(1,m)} & 0 & \cdots & 0 & \tilde{\omega}_{22}^{(1,m)} & \cdots & \tilde{\omega}_{25}^{(1,m)} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{\omega}_{15}^{(1,m)} & 0 & \cdots & 0 & \tilde{\omega}_{25}^{(1,m)} & \cdots & \tilde{\omega}_{55}^{(1,m)} \end{bmatrix},$$

where $\tilde{\omega}_{rs}^{(k,m)}$ is the element on the *r*-th row and *s*-th column of the inverse of $\Omega_k^{(m)}$.

The second conditional maximization estimates $\Omega_k^{(m+1)}$ by maximizing $\ell^c \left(\boldsymbol{\beta}^{(m+1)}, \Omega_0, \Omega_1 \mid \boldsymbol{y} \right)$ with respect to the elements in the Ω_k conditional on $\boldsymbol{\beta}^{(m+1)}$ and $\Omega_k^{(m)},\ k = 0,1$. We obtain the optimizers by solving numerically the first order conditions $\Omega_k^{(m+1)} - \frac{1}{N} \sum_{i=1}^{N} Q_i^k \left(\boldsymbol{\beta}^{(m+1)} \mid \boldsymbol{\beta}^{(m)}, \Omega_k^{(m)}, \boldsymbol{y} \right) = 0$ subject to the normalization constraints $\omega_{11}^{(k,m+1)} = 1 \quad k = 1,0$. The procedure is then repeated until convergence is attained.

It remains the implementation of the Gibbs sampler (Casella and George, 1992) necessary to estimate the matrices Q_i^k. The sampler requires the distribution of each vector $\boldsymbol{y}_j^{*k}$ conditional on the value of dependent variables other than $\boldsymbol{y}_j^{*k}$, i.e. the distribution of $\boldsymbol{y}_{j|-j}^{*k}$. These are univariate normal under the normality assumption with means and variances at the $m+1$ iteration equal to

$$\mu_{ji|i(-j)}^{(k,m)} = X_{ji}\beta_j^{(k,m)} + \operatorname{cov}\left(y_{ji}^{*k}\left|\boldsymbol{y}_{i|-j}^{*k},\Omega_k^{(m)}\right.\right)\left[\operatorname{cov}\left(y_{ji|-j}^{*k}\left|\Omega_k^{(m)}\right.\right)\right]^{-1}\left(\boldsymbol{y}_{i|-j}^{*k} - \boldsymbol{X}_{i|-j}\boldsymbol{\beta}_{-j}^{(k,m)}\right)$$

$$\sigma_{j|-j}^{2(k,m)} = \operatorname{var}\left(y_{ji}^{*k}\left|\Omega_k^{(m)}\right.\right) - \operatorname{cov}\left(y_{ji}^{*k}\left|\boldsymbol{y}_{i|-j}^{*k},\Omega_k^{(m)}\right.\right)\left[\operatorname{cov}\left(y_{ji|-j}^{*k}\left|\Omega_k^{(m)}\right.\right)\right]^{-1}\operatorname{cov}\left(y_{ji}^{*k}\left|\boldsymbol{y}_{i|-j}^{*k},\Omega_k^{(m)}\right.\right)'$$

The y_{ji}^{*k} must be simulated conditional on its corresponding observed information y_{ji}. The observed counterpart of y_{1i}^{*} is dichotomous with y_{1i}^{*} being positive if y_{1i} equals one and non-positive if y_{1i} equals zero. Accordingly, we simulate y_{1i}^{*} from a normal distribution with mean $\mu_{1i|i(-1)}^{(m)}$ and variance $\sigma_{1i|-1}^{2(m)}$ truncated below at zero if y_{1i} equals one and truncated above at zero if y_{1i} equals zero. Variables y_{ji}^{*k} $(j=2,3,4,5)$ are all censored from below at zero and from above at one. Thus, the unobserved components must be simulated from normal distributions with means $\mu_{ji|i(-j)}^{(k,m)}$ and variances $\sigma_{ji|-j}^{2(k,m)}$ truncated above at zero if $y_{ji}=0$ and from normal distributions truncated from below at one if $y_{ji}=1$. If $0<y_{ji}<1$, $y_{ji}^{*k}=y_{ji}$. Terms $\sigma_i^{2(k,m)}$ and $\mu_{y_{ji}^{k*}}^{(k,m)}$ are then estimated from the simulated samples and used to calculate $Q_i^k\left(\beta\,|\,\beta^{(m)},\Omega_k^{(m)},\boldsymbol{y}\right)$.

Information matrix

Louis's identity (Louis, 1982) was used to obtain the information matrix

$$I(\theta;\boldsymbol{y}) = -H^c(\theta;\boldsymbol{x}) - E\left[S^c(\theta;\boldsymbol{x})S^c(\theta;\boldsymbol{x})'\right] + E\left[S^c(\theta;\boldsymbol{x})\right]E\left[S^c(\theta;\boldsymbol{x})'\right]$$

where $H^c(\theta;\boldsymbol{x})$ and $S^c(\theta;\boldsymbol{x})$ are the Hessian and Score vector of the complete information log-likelihood, respectively, which are well known for the normal distribution. All the expectations are estimated at the final MCEM estimators. We use Monte Carlo estimates of the complete information Hessian and score to estimate the information matrix (for details see Natarajan, McCulloch, and Kiefer, 2000).

Appendix 3. Parameter estimation results

Equation	Variable	Estimate	Std. error
Cost-Sharing	Constant	0.7802 [c]	0.4096
	CSAge	-0.0369 [a]	0.0057
	Education	-0.3293 [c]	0.1841
	Slope	0.3503	0.2297
	Rented	-0.8398 [a]	0.2730
	Land	0.7089 [a]	0.2172
	Distance	-0.0393 [c]	0.0208
	NC	0.0457	0.2356
	UES	0.4740	0.2899
	LES	0.1393	0.3101

		Regime $y_{1i}=0$		Regime $y_{1i}=1$	
Equation	**Variable**	**Estimate**	**Std. error**	**Estimate**	**Std. error**
Vegetative Cover	Constant	0.1294	0.1081	-0.3583	0.3072
	Age	0.0015	0.0015	0.0124 [b]	0.0048
	Education	0.0406	0.0392	0.1310	0.1185
	Slope	-0.0493	0.0480	0.5019 [a]	0.1519
	Rented	-0.1900 [a]	0.0639	0.5363 [b]	0.2488
	Land	-0.0861	0.0668	-0.1481	0.2052
	NC	0.3547 [a]	0.0484	0.1939	0.1442
	UES	-0.1646 [b]	0.0724	0.0280	0.1850
	LES	-0.2964 [a]	0.0711	-1.0766 [b]	0.4540
Contour/ Strip cropping	Constant	-0.5720 [a]	0.1310	-0.1192	0.3173
	Education	-0.1592	0.1112	0.1652	0.2120
	Slope	0.7382 [a]	0.1357	0.7491 [b]	0.3006
	Rented	0.5029 [a]	0.1550	1.0790 [b]	0.4380
	Land	-0.2192	0.1629	-0.2264	0.3497
	NC	0.0008	0.1314	0.7654 [a]	0.2641
	UES	0.0281	0.1824	0.0632	0.3677
	LES	-0.6607 [b]	0.2632	0.1087	0.4776
Cover crops	Constant	-0.1035	0.0819	0.0413	0.1667
	Education	0.0663	0.0668	-0.1282	0.1194
	Slope	-0.1012	0.0873	-0.0857	0.1539
	Rented	0.2564 [a]	0.0973	-0.0400	0.1798
	Land	-0.1257	0.1028	0.1795	0.1377
	NC	-0.1166	0.0841	-0.2912 [a]	0.1253
	UES	-0.0552	0.1119	-0.2479	0.1761
	LES	-0.1529	0.1109	-0.1756	0.2021
Minimum/ No tillage	Constant	-0.3589 [a]	0.1156	0.0676	0.1974
	Education	-0.3241 [a]	0.0912	0.0662	0.1326
	Slope	0.2996 [a]	0.1110	0.0425	0.1765
	Rented	0.7079 [a]	0.1277	0.5996 [a]	0.2284
	Land	-0.0498	0.1406	0.1059	0.1763
	NC	0.0061	0.1161	-0.0707	0.1502
	UES	0.3039 [b]	0.1465	-0.0816	0.2124
	LES	0.1973	0.1491	-0.1754	0.2517

Equation	Variable	Estimate	Std. error	Estimate	Std. error
Covariance matrix	ω_{12}	0.1221 [a]	0.0099	-0.4306 [a]	0.0139
	ω_{13}	-0.2511 [a]	0.0243	-0.6370 [a]	0.0303
	ω_{14}	-0.1942 [a]	0.0156	0.2076 [a]	0.0195
	ω_{15}	-0.5873 [a]	0.0078	0.0483 [c]	0.0275
	ω_{22}	0.0823 [a]	0.0041	0.2168 [a]	0.0125
	ω_{23}	0.0198 [a]	0.0069	0.2511 [a]	0.0144
	ω_{24}	0.0143 [a]	0.0045	-0.1036 [a]	0.0105
	ω_{25}	-0.0541 [a]	0.0059	-0.0675 [a]	0.0140
	ω_{33}	0.4532 [a]	0.0246	0.5543 [a]	0.0434
	ω_{34}	0.1730 [a]	0.0128	-0.0754 [a]	0.0141
	ω_{35}	0.1171 [a]	0.0146	0.0064	0.0211
	ω_{44}	0.1971 [a]	0.0106	0.1057 [a]	0.0112
	ω_{45}	0.0992 [a]	0.0093	0.0627 [a]	0.0108
	ω_{55}	0.3811 [a]	0.0093	0.1278 [a]	0.0155

[a] Significant at 1% significance; [b] significant at 5% significance; [c] significant at 10% significance

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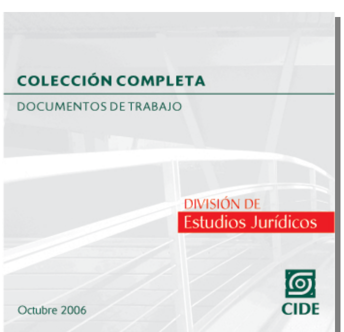

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