A Model of Agricultural Land Use, Costs, and Water Quality in the Chesapeake Bay

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1. Introduction

Nonpoint source pollution from agriculture is the largest source of impairment in U.S. rivers and streams (U.S. EPA 2009). The primary policy instrument used to address this problem is cost sharing, a subsidy offered at both the state and federal levels to share the fixed cost of adopting qualifying best management practices (BMPs) intended to increase efficiency and reduce nutrient loading in rivers and streams. For example, the federal Environmental Quality Incentives Program (EQIP) spent \$1.38B in 2012 to subsidize agricultural conservation practices. In Maryland, the Maryland Agricultural and Water Quality Cost Share (MACS) program spent \$26.7M in 2013, of which \$20.8M was directed towards a single BMP, cover crops.

However, understanding the causal effect of cost share programs on conservation behavior is complicated by several factors. First, cost sharing programs are subject to the problem of adverse selection, in which the farmers most likely to adopt conservation practices on their own accord are also more likely to apply for cost share funds (Claassen et al. 2012). Second, damages that result from agricultural runoff depend on the amount actually reaching waterways, making it difficult to measure how small changes in farmer behavior translate to water quality benefits (Kling 2011; Kling et al. 2014). Finally, patterns of substitution among certain conservation practices (Lichtenberg 2004a, Lichtenberg & Smith-Ramirez 2011) may cause a subsidy for one practice to "crowd out" or exclude other environmentally benign practices.

This paper investigates the effect of cost sharing for cover crops on the acres of conservation activity on a farm, paying particular attention to patterns of correlation and substitution in a group of erosion-control BMPs. Lichtenberg and Smith-Ramirez (2011), Lichtenberg (2004b), and Khanna et al. (2002) present an economic model of why cost share subsidies may lead to "slippage", or the replacement of environmentally benign land uses (such as pasture or woodland) with more intensive cultivation. Yet even among practices used to reduce erosion on cultivated land, there are agronomic and economic reasons to expect interaction among various BMPs, including a group of erosion-control practices studied here: cover crops, conservation tillage, and contour-strip farming. For this reason, the heavy subsidies devoted to cover crops may have indirect effects on the use of other BMPs. It is essential to know what these indirect effects are in order to grasp the overall effect of cost share on the suite of conservation practices used by a farm and, in turn, its effect on potential water quality benefits.

Empirical estimation of the effectiveness of cost sharing has followed two general lines: simultaneous estimation of a system of equations (Lichtenberg & Smith-Ramirez 2011; Cooper 2003; Dorfman 1996) and propensity score matching (Mezzatesta et al. 2013; Claassen & Duquette 2012). The approach taken here is the former. While matching techniques are useful for identifying the direct effects of cost sharing on the use of a particular BMP, simultaneous equation estimation is better suited for capturing correlation in BMP use and the potential indirect effects of cost share. Specifically, BMP acreage is simultaneously estimated for three erosion-control practices—cover crops, conservation tillage, and contour-strip farming—using a recent survey of 523 Maryland farmers. Since it is not possible to allocate less than zero acres to a BMP, the likelihood functions for the BMP acreage equations are considered to be censored from below. Simulated maximum likelihood (ML) estimation with pseudorandom Halton sequences is employed to evaluate the multi-dimensional normal integrals in the likelihood function of the three censored BMP acreage equations (Train 1999). Receipt of cost sharing is also simultaneously estimated for each of the three practices using simulated ML estimation. To correct for self-selection bias, the inverse Mills ratios from the cost share equations are used as covariates in the system of BMP acreage equations.

Along with the farmer survey, geo-spatial information from the *Chesapeake Bay Program's* (*CBP's*) most recent Phase 5.3 watershed model is used to estimate water quality benefits due to the direct and indirect effects of cost sharing. Costs of cover crop cost share are combined with tributary-specific data on agricultural pollution loads, and the ratios of pollution transported to the Bay from over 900 river segments in Maryland, to calculate the cost effectiveness of cost share given representative cover crop incentive payments in the state. This is a highly useful metric for policymakers, economists, and anyone concerned with nonpoint source pollution abatement.

The results found here indicate that the heavy subsidies for cover crops in Maryland increased the use of cover crops among treated farmers, and indirectly increased the use of conservation tillage; however, they indirectly decreased the use of contour-strip farming. Among untreated farmers, on the other hand, subsidies for cover crops are projected to have unambiguously positive effects. Acreage in cover crops, conservation tillage and contour-strip farming would all be expected to increase (albeit to a smaller degree) as a result of extending cost share to those not currently receiving the subsidy.

By fully accounting for correlation in the BMP adoption decisions of various erosion-control practices — and to the extent that these results are generalizable to different regions of the country — extending cost share for cover crops to the untreated farms is a potentially cost effective way to reduce both nitrogen and phosphorus runoff, in comparison to other proposed abatement methods.

2. Institutional Background

2.1 Correlation in cover crop, no-till, and contour-strip farming BMPs

Farmers use multiple BMPs for many reasons, but the primary factor leading to multi-BMP adoption is variability: topography, soil drainage, and production methods often vary within a farm. In the mid-Atlantic region of the United States, for example, many farms have hilly areas not suitable for cultivation of crops, as well as moderately sloped areas that work well with certain BMPs, as well as flat areas that are best suited for other BMPs or no BMPs at all. This variability makes it optimal to adopt bundles of conservation practices, rather than a single practice best-suited for all farms throughout the region and throughout the year (Lichtenberg 2004a; Dorfman 1996).

Among practices used to reduce erosion on cultivated land, there are agronomic and economic reasons to expect interaction among various BMPs, including the three practices studied here: cover crops, conservation tillage, and contour-strip farming (see **Appendix 1** for descriptions of these practices).

First, cover crops and conservation tillage are often adopted jointly. Potential complementarities between these practices have long been studied (Reeves, 1994). There is evidence that cover crops contribute to the efficiency of conservation tillage systems. This may happen through at least two agronomic mechanisms: by adding increased organic matter to the soil and stimulating soil biological activity (USDA SARE, 2012); and due to the increased need for crop rotation in order to maintain productivity in conservation tillage systems. Similarly, there is some agronomic evidence that conservation tillage contributes to the efficiency of cover crops. For example, suppression of weeds can be better if cover crops are managed with reduced tillage systems (Blum et al., 1997). More importantly, however, conservation tillage methods improve the management efficiency of cover crops: no- or low-till methods reduce the time required to plant during the fall season—when a farmer's ability to work her fields is already severely limited due to weather and the competing demands of harvest. Accordingly, the heavy subsidies directed to cover crops by *MACS* may have indirect effects on a farmer's adoption of conservation tillage methods.

Contour farming and strip farming, as discussed in **Appendix 1**, are two distinct practices that are often used jointly. However, the widespread adoption of conservation tillage among crop farmers may substitute for these two traditional practices. In conservation tillage systems, the soil structure is left intact, and sloped fields become significantly less vulnerable to erosion. This may allow farmers to avoid the costs involved in contour-strip farming once they have adopted conservation tillage. Indeed, in the revised universal soil loss equation, there are diminishing returns in erosion reduction efficiency with the simultaneous adoption of contour-strip farming and conservation tillage (RUSLE2, 2013). This suggests a potential second-order mechanism by which cover crop cost sharing may reduce land in contour-strip farming: cover crop cost sharing may increase adoption of no-till, which in turn substitutes land away from contour-strip farming.

For these reasons, the heavy subsidies devoted to cover crops will likely have indirect effects on the use of other erosion-control BMPs. It is important to know what these indirect effects are in order to grasp the overall effect of cost share on the suite of conservation practices used by a farm. There may be indirect benefits, or indirect costs, which increase or decrease the effectiveness of agricultural incentive payments. To measure the magnitude of benefits to water quality, it is important to account for indirect effects whenever possible.

2.2 Cost sharing in the study region

What is the institutional structure of cost sharing in Maryland? **Figure 1** depicts the spending levels in Maryland of the most common agricultural conservation programs utilized by farmers in the state, from 2009 to 2013.

The largest program that funds practices on working land across the United States, and the second largest in Maryland, is the federal Environmental Quality Incentives Program (*EQIP*). Established by the 1996 farm bill, this program provides financial—but also technical and educational—assistance to promote environmental quality and production on working farm land. In 2012, *EQIP* had total fiscal obligations in Maryland of about $10M.

The Chesapeake Bay Watershed Initiative (*CBWI*) is an additional federal source of funding for agricultural producers within the Chesapeake Bay watershed. Authorized by the 2008 farm bill, $23M in funding was available in 2009, rising to a maximum of $72M in 2011, of which nearly $15M was spent on BMPs in Maryland. The initiative is administered through *EQIP*, and all *EQIP* requirements and policies apply.

At the state level, the Maryland Agricultural Water Quality Cost Share (*MACS*) program is the largest source of funding for BMPs. In 2013, *MACS* spent about $26.7M to incentivize the adoption of conservation practices. More than 80% of funding was directed to cover crops.

Like all cost share programs, farmer participation in *MACS* is voluntary. Yet its increasing usefulness as a policy instrument is driven in part by the Chesapeake Bay Total Maximum Daily Loads (*TMDLs*), a pollution diet instituted for the entire Chesapeake Bay watershed by the U.S. EPA in 2010. Following the 1992 Clean Water Act, the term *TMDL* originally applied to point-source (PS) pollutants. However, it has since received broader application to include non-point source (NPS) pollution from agriculture. In September of 2013, a federal judge rejected a legal challenge to the Chesapeake Bay *TMDL*[1], implying increasing scrutiny of agricultural NPS pollution in the coming years.

The Chesapeake Bay *TMDL* defines maximum allowable levels of runoff of nitrogen, phosphorus, and sediment into the Chesapeake Bay for each state jurisdiction in the watershed by 2025. Cost sharing is currently the primary policy instrument being used in these jurisdictions, including Maryland, to curb agricultural NPS pollution and achieve the *TMDL* goals.

3. Conceptual Model – Cost Share Award, Application and BMP Adoption Decisions

An empirical study of cost share and adoption of multiple BMPs requires careful thought on the interaction between the farmer's conservation decision and cost share application decision. These decisions occur simultaneously, as a farmer is faced with an adoption decision and a corresponding cost share decision for each practice under consideration.[2]

3.1 BMP Adoption

[1] American Farm Bureau Federation, et al. v. United States Environmental Protection Agency, et al., 9/13/2013, 1:11-CV-0067

[2] In the farmer survey used for the empirical analysis, the cost sharing application and award decisions are not separately observed, but only whether or not cost sharing was received for each farmer. Thus, empirical estimation of cost share receipt requires combining the application and award decisions into a single step. Given the institutional background of cost sharing in Maryland, this empirical limitation is not as restrictive as it might seem. In the case of *MACS*, which is the dominant funding source of cover crops in Maryland, eligible farmer-applicants have never been turned down for cost sharing for cover crops (*Conversation with* MACS *Program Administrator Norman Astle, 07/5/12*). In these cases, econometric estimation of cost share receipt will primarily capture those factors influencing the farmer's likelihood of application.

First, consider the BMP adoption decision of farmer j for any BMP in a group of three erosion-control practices. Note that farms differ in operating acreage, A_j, and have a continuous variation of land quality $q \epsilon [0,1]$, which is inversely proportional to erosion vulnerability. For simplicity, q can be thought of as a measure of topography, where $q = 1$ is completely flat and $q = 0$ is very steeply sloped. The heterogeneity in land quality within a farm makes it optimal for farmers to diversify crops and BMPs.

If a farmers' objective is to maximize profits, the adoption decision can be represented in a straightforward way. Let $a_{j,m}(q)$ indicate a farm's *proportion of operating acres* of a given quality that is allocated to BMP $m = \{1,2,3\}$.[3] Let $\pi_j(q)$ indicate per-acre profits at the same land quality. Then total farm profit, denoted as Π_j, is simply the sum of per-acre profits in each BMP multiplied by the total acres, aggregated over all the land qualities present on the farm:

$$\Pi_j = A_j \cdot \int_{q=0}^{q=1} \{\sum_{m=1}^{3} \pi_{j,m}(q) \cdot a_{j,m}(q)\}\, dq \tag{3.1}$$

$$\text{where } \sum_{m=1}^{3} a_{j,m}(q) \leq \frac{A_j(q)}{A_j},$$

$$\text{and } \int_{q=0}^{q=1} a_j(q) dq = 1 .$$

For concreteness, consider a profit function specified in the following form:

$$\pi_{j,m}(q) = P \cdot f\big(e_m(q) x_{j,m}, H_j\big) - w x_{j,m} - k_m . \tag{3.2}$$

Here, P is a vector of prices for agricultural outputs, $f(\cdot)$ is a concave production function increasing in its arguments, $x_{j,m}$ are variable inputs, $e_m(q)$ is the efficiency with which the chosen BMP converts inputs to outputs for a given land quality, H_j is a measure of the farmer's human capital, w is a vector of variable input costs which may vary by land use, and k_m is the per-acre fixed cost of adopting a certain BMP ($k_m = 0$ when BMP m is not adopted).[4]

The farmer's decision, then, is to choose the share of land on which to adopt a given BMP, a decision implicitly defined by the first order conditions of the profit-maximization problem.

$$\pi_{j,m}\big(q, P, w, H_j\big) - \pi_{j,-m}\big(q, P, w, H_j\big) \geq 0, \tag{3.3}$$

That is, a BMP will be adopted on land of quality q when the profit from doing so exceeds the profit from not doing so (the term $-m$ indicates that BMP m is not adopted). Recalling the functional form in equation **3.2**, adoption of BMP m on land of a given quality is decreasing in per-acre *fixed* costs of BMP

[3] For simplicity of notation, assume for the time being that each BMP is mutually exclusive. In reality, the three BMPs considered here—cover crops, no-till, and contour-strip farming—may be adopted jointly.

[4] BMP adoption involves both initial fixed costs as well as variable costs over time. For example, switching to no-till substitutes the on-going variable costs of labor and fuel for the initial fixed cost of machinery. On the other hand, use of cover crops increases the variable costs of planting in the fall for the long-term benefits of soil fertility (i.e. a higher $e_m(q)$). Thus, it is helpful to think of the overall cost of BMP adoption as representing not only initial fixed costs, but the discounted present value of costs over time.

adoption, and increasing in the cost of *variable* inputs used less intensively under BMP m (e.g. labor or fuel in the case of no-till).

Now consider the possibility that the three BMPs may be adopted jointly. Patterns of substitution or complementarity among BMPs will then be reflected implicitly in the first order condition shown in **3.3**. For example, consider the cost of improving soil fertility with a given BMP, such as no-till. If adoption of another related BMP, such as cover crops, decreases the cost of improving soil fertility by adding increased organic matter to the topsoil, adoption of no-till would implicitly increase due to the adoption of cover crops. The pattern of complementarity would be reflected in the cross-price elasticity between these two practices. Similarly, any patterns of substitution in the erosion reduction efficiencies between practices (e.g. no-till and contour-strip farming, as discussed above) would be reflected implicitly in these first order conditions.

When a farmer receives cost share, the terms of her BMP adoption decision change. The profit function, described above in equation **3.2**, increases by the per-acre amount of the cost share award:

$$\pi_{j,m}(q) = P \cdot f\big(e_m(q)x_{j,m}, H_j\big) - wx_{j,m} - k_m + CS_{j,m}. \tag{3.4}$$

Here, $CS_{j,m}$ is the cost share award for BMP m. Recalling the first order conditions determining the adoption decision, a farmer's adoption of BMP m is increasing in the amount of the cost share award received. However, receipt of cost share for another BMP will affect adoption of m only through possible changes in the variable inputs or fixed costs of adopting these BMPs together. For example, cost share for cover crops will increase the amount of land in cover crops, but it may also increase the amount of land in no-till if there are patterns of complementarity between the two practices.

Finally, heterogeneity of land quality q within a farm implies that the BMP adoption decision is not binary, but continuous with the acres on a farm. This adds realism to the modeling structure in important ways. Not only the BMP adoption decision, but also the cost share application decision are dependent in important ways on farm land quality, q.[5]

The group of BMPs analyzed—cover crops, conservation tillage, and contour-strip farming—all benefit farmers by reducing erosion. **Figure 2** contains a graphical depiction of the interaction of related, erosion-control BMPs. Adoption of a BMP that reduces the fixed cost of adopting a related BMP has an equivalent effect as that of cost sharing, causing a parallel upward shift in the farmer's expected profit per acre of crop production, e.g. adopting no-till reduces the fixed cost of planting cover crops in the fall (see the left-hand side of **Figure 2**). If adoption of a BMP contributes to the erosion-reduction efficiency of another BMP for any given q, then the slope of the profit per acre function increases, e.g. adopting cover crops helps build soil structure in a no-till system (see the right-hand side of **Figure 2**). Finally,

[5] In theory it is also possible to "intensify" the use of an erosion-control BMP on a given acre of land (e.g. cover crops, by planting earlier, more densely, etc.). In this regard, BMP costs, profit, and cost share amounts all become functions of the intensity of BMP use on farm j. In what follows, this paper will assume that the BMPs studied here—cover crops, contour-strip farming, and no-till—are either present on an acre of land or not. The implications of this assumption for policy relevance are important to bear in mind.

adoption of a BMP that substitutes with another in improving land quality would decrease the slope in the same line (e.g. adopting contour-strip farming and no-till).

In empirical specification, the most general method of evaluation of multi-BMP adoption would be simultaneous estimation that allows unconstrained correlation in the variance-covariance matrix of error terms, Ω. Correlation would be expected not only between each of the three BMP adoption equations, and not only between each of the three cost share equations, but also between each cost share and BMP adoption equation. Descriptions of the data and empirical specification follow.

4. Data

The effect of cost sharing on conservation and non-point source pollution is analyzed empirically with data from two primary sources: micro-level data from a survey of 523 Maryland farmers commissioned by the University of Maryland (UMD); and geo-spatial information from the Chesapeake Bay Program's (CBP's) most recent Phase 5.3 watershed model.

1. The UMD survey was administered by USDA's National Agricultural Statistics Service (NASS) via computer-assisted telephone in 2010. Stratified random sampling ensured a sufficient number of responses from large operations, and sampling weights were provided by NASS for deriving population estimates. The present analysis uses data from 451 farms that provided complete surveys. Farmers were asked whether they used any of 12 different conservation practices, the acreage upon which the practices are implemented, and whether or not cost sharing was received to incentivize adoption. Included in the survey were the erosion-control practices of conservation tillage (referred to subsequently as "no-till", though conservation tillage includes a wider range of practices than purely no-till), cover crops, and contour-strip farming. The survey also elicited information on land quality (topography), farm operating acreage, farm zip code, human capital considerations (farmer education and age), and other farm characteristics . Farmer conservation decisions with and without cost share funding are shown in **Table 1** for the erosion-control practices studied. Columns [1] to [3] show the number of farms (unweighted) in the UMD survey in each category. Only for cover crops do more farmers adopt with the help of cost share funding than without. Columns [4] and [5] show that, among the surveyed farms that adopted cover crops, those who adopted with the help of cost share allocated more acres to the practice. However, this is not the case for no-till.

   The study region includes all Maryland counties. Maryland is a favorable location in which to study the question of the indirect effects of cost sharing on the overall mix of practices used on a farm for several reasons. Variable production conditions lead most Maryland farmers to adopt multiple conservation practices and land uses, many times without cost sharing assistance. Secondly, Maryland has been aggressive in promoting cost sharing for cover crops, which has had a substantial effect on farmer behavior. Independent estimates indicate that 60% of crop farmers in Maryland used cover crops over the 2012-2013 winter season. In part, this was due to the fact that 40% of crop farmers in the state received cost sharing for the practice that year

(Union of Concerned Scientists, 2013). In fact, Maryland's effort to incentivize cover crop adoption is at times depicted as a model for other states in the Chesapeake Bay watershed to follow.[6]

2. The CBP Phase 5.3 watershed model provides publically accessible data related to the Chesapeake Bay (available here: http://www.chesapeakebay.net/data). Tributary- specific data on agricultural pollution loads, and the ratios of pollution delivered to the Bay from over 900 river segments in the state of Maryland, are combined with variable BMP reduction efficiencies to calculate the pounds of nonpoint source pollution reduction achieved and achievable with cost share for cover crops.

   Finally, a measure of erosion-reduction cost for each farm and each BMP is derived by combining BMP costs per acre (which are fixed across the state) with geographically-varying data from the CBP watershed model. Specifically, BMP installation and O&M costs per acre are divided by estimated erosion-reduction per acre from these BMPs: where erosion-reduction per acre is calculated as the edge-of-field agricultural sediment load in a river segment multiplied by the BMP reduction efficiency in that river segment. Per-acre costs are from Wieland et al. (2009) for cover crops, Maryland grain marketing budgets for no-till, and *EQIP* reimbursement rates for contour-strip farming. Agricultural sediment loads vary throughout the Bay watershed by river segment, and BMP reduction efficiencies vary by hydrogeomorphic region, which causes the derived measure of cost (per pound of erosion reduced) to vary cross-sectionally across the state of Maryland. These variable costs are matched with farmers in the *UMD* survey using farmer zip code. The erosion-reduction cost, while not capturing every aspect of BMP cost, is especially relevant for farmers considering the implementation of practices designed to reduce erosion, such as those considered in this study. **Table 2** shows descriptive statistics for all the variables used in the econometric analysis.

5. Estimation Method

As mentioned, empirical estimation of the effectiveness of cost sharing has followed two general lines: simultaneous estimation of a system of equations (Lichtenberg & Smith-Ramirez 2011; Cooper 2003; Dorfman 1996) and propensity score matching (Mezzatesta et al. 2013; Claassen & Duquette 2012). The approach taken here is the former. Specifically, BMP acreage is simultaneously estimated for the three practices studied—cover crops, no-till, and contour-strip farming. The following sections describe the estimating equations in more detail for the cost sharing and BMP acreage equations.

5.1 Cost share

Consider first the cost sharing decision. As noted, the survey used for empirical analysis does not record the cost share application and award decisions separately. Only a binary indicator of cost share receipt

[6] The Baltimore Sun. Tim Wheeler. *Maryland farmers set cover crop record – with an asterisk*. February 2, 2011.

is reported by the farmer. Empirical estimation of cost share receipt will therefore combine both the (farmer's) application and the (agency-regulator's) funding decision. As evident from the prior discussion, cost share receipt depends on factors entering both the award decision and the application decision, including expected benefits of the BMP, the agency budget, BMP costs, and transaction costs. If these variables enter the model linearly, a functional representation of the cost-share decision is:

$$CS_j = 1 \quad if \quad Z_j\gamma + u_j \geq 0$$
$$CS_j = 0 \quad if \quad Z_j\gamma + u_j < 0 \qquad (5.1)$$

where Z_j are the factors influencing the award and application decisions for farmer j; γ is a vector of parameters to be estimated; and u_j is an error term.

Note that farmers who receive cost sharing for one conservation practice may be more likely to receive cost sharing for other practices. Unobserved farm and farmer characteristics and reduced marginal transaction costs for making additional applications may contribute to positive correlation in the error terms of the cost share equations for each of the three practices studied.

For these reasons, the cost share equations for cover crops, no-till, and contour-strip farming are estimated simultaneously. The variance-covariance matrix of error terms for each of the $m = \{1,2,3\}$ practices will be unrestricted.

$$CS_{jm} = 1 \quad if \quad Z_{jm}\gamma_m + u_{jm} \geq 0, \qquad m = \{1,2,3\} \qquad (5.2)$$
$$CS_{jm} = 0 \quad if \quad Z_{jm}\gamma_m + u_{jm} < 0, \qquad m = \{1,2,3\}$$

where,

$$\Omega_{cs} = Var\begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix} = \begin{pmatrix} \sigma_1^2 & \sigma_{21} & \sigma_{31} \\ \sigma_{12} & \sigma_2^2 & \sigma_{32} \\ \sigma_{13} & \sigma_{23} & \sigma_3^2 \end{pmatrix} \qquad (5.3)$$

Here, Ω_{cs} is the 3x3 variance-covariance matrix of error terms of the cost-share equations for cover crops, contour-strip farming, and no-till. If the error terms are distributed jointly normal, the system of equations represented in equations **5.2** and **5.3** can be solved as a trivariate probit.

I estimate the 3-equation probit model by simulated maximum likelihood (ML) using the Stata package 'mvprobit' (see Cappellari and Jenkins (2003)). The variance-covariance matrix of the cross-equation error terms (Ω_{cs}) has values of 1 on the leading diagonal. The off-diagonal elements are estimated through Cholesky factorization, where

$$\hat{\rho}_{lk} = \hat{\sigma}_{lk}/\hat{\sigma}_l\hat{\sigma}_k \qquad (5.4)$$

is estimated as the correlation between receiving cost share for BMPs l and k. The Geweke-Hajivassiliou-Keane (GHK) simulator (see Greene 2003, p. 931-933) is used to evaluate the 3-dimensional normal integrals in the likelihood function associated with equations **5.2** and **5.3**. As described in

Greene, the GHK simulator requires estimating a likelihood contribution for each observation within each random draw, R, of the simulation. The observation's estimated contribution is then the average of the values derived across all random draws. (See also Train (2009)). With these simulated contributions in hand, estimation can proceed by standard ML techniques. The algorithm's stopping rule is defined by convergence of the likelihood function (1e-7), the vector of parameter estimates (1e-6), and the scaled gradient vector (1e-4). Monte Carlo experiments show that the GHK estimates are consistent when $R \geq \sqrt{N}$ (Cappellari and Jenkins, 2003). Here, I set $R = 50$, which is well above the square root of the sample size.

5.2 BMP adoption

Self-selection is a well-known problem that complicates empirical estimation of the effect of cost share (Claassen et al., 2012). The farmers most likely to apply for cost sharing are also the ones most likely to adopt conservation practices on their own accord, making it difficult to identify the causal effect of the cost share subsidy. One common way to correct for the problem of self-selection in program evaluation is through the use of the inverse Mills ratio. This technique was originally developed in the field of labor economics in order to correctly evaluate the effectiveness of voluntary job training programs (Heckman 1979). However, the case of cost share is analogous. In both cases, unobservable traits that make one person more likely than another to enroll in a program must be accounted for in order to evaluate the program's effect on an outcome variable of interest (e.g. wages in one case, adoption of conservation practices in the other).

Inverse Mills ratios can be obtained after estimating the cost share decision for each BMP, as described above. Specifically, the inverse Mills ratio for conservation practice m is estimated as:

$$\hat{\lambda}_{jm}^{1} = \frac{f(Z_{jm}\hat{\gamma}_m)}{F(Z_{jm}\hat{\gamma}_m)} if\ CS_{jm} = 1$$

$$\hat{\lambda}_{jm}^{0} = \frac{-f(Z_{jm}\hat{\gamma}_m)}{F(-Z_{jm}\hat{\gamma}_m)} if\ CS_{jm} = 0. \quad (5.5)$$

Here, $f(\cdot)$ and $F(\cdot)$ represent the normal probability and cumulative densities, respectively, and $\hat{\gamma}_m$ is the vector of estimated parameters for cost sharing for practice m, as described above. The ratios, when inserted as regressors in the BMP acreage equations, allow for consistent though not efficient estimation of the effect cost share. As Heckman showed, the estimated coefficient associated with this regressor is precisely the covariance of error terms between the selection (i.e. cost share) and outcome (i.e. acreage) equations, based on the assumption that these errors are distributed jointly normal.

I estimate BMP acreage equations in an endogenous switching regression framework simultaneously for three erosion-control practices: cover crops, no-till, and contour-strip farming. The observed cost share indicator for cover crops determines which regime the farmer faces in the BMP acreage decision. Let superscripts indicate the regime. Then

$$\text{Regime 1:}\ \ a_{jm}^{1} = X_{jm}\beta_m^{1} + \sum_{m=1}^{3} \delta_m^{1}\hat{\lambda}_{jm}^{1} + \varepsilon_{jm}^{1} \quad if \quad CS_{j1} = 1 \quad (5.6)$$

$$\text{Regime 0:}\quad a_{jm}^0 = X_{jm}\beta_m^0 + \sum_{m=1}^{3}\delta_m^0\hat{\lambda}_{jm}^0 + \varepsilon_{jm}^0 \quad if \quad CS_{j1} = 0.$$

Note that cost share for cover crops was used to determine regime-switching. This was done for two reasons. First, cover crops are by far the most heavily subsidized practice in the study region[7], therefore policymakers are interested in understanding the particular effect of cover crop cost sharing. Second, in our survey, cost share is rarely used for the other erosion-control practices studied ($n = 10$ for contour-strip farming; $n = 27$ for no-till), which leads to problems of insufficient sample size in the switching regression framework.[8]

In equation **5.6**, X_{jm} are variables that influence the acreage decision for BMP m, and β_m^i, $i = \{0,1\}$ are coefficients to be estimated separately for each of the two regimes. For purposes of identification, the vector Z_{jm} from equation **5.2** must contain some variables not included in X_{jm}: these are variables influencing the cost share decision but not the BMP acreage decision.

The switching regression framework has previously been utilized in the cost share literature (Lichtenberg & Smith-Ramirez 2011). An advantage of this framework in comparison to other methods is its generality. Parameter estimates are allowed to vary based on a farmer's cost share status ($\beta_k^1 \neq \beta_k^0$), which is a possibility that should not be precluded in advance, especially for regressors related to the cost of BMP adoption.

On the other hand, it is not necessarily the case that the parameters will differ across regimes. I use a Wald test to measure the appropriateness of switching for each regressor individually when there is no prior theoretical reason to expect parameter differences across regimes. For example, the effect of a farmer's age on the acres of BMP adoption would likely be similar across regimes. Moreover, the computational difficulty of solving systems of equations with only a few hundred observations—as is usually the case with farm conservation surveys—makes it advantageous to limit the number of estimated parameters whenever possible. For these reasons, when no statistical difference is observed empirically, and no difference is expected conceptually (as is the case with the independent variables related to cost), the parameter estimate associated with that regressor is constrained to be equal across regimes.

The dependent variable a_{jk} is censored from below at zero, since it is not possible to allocate less than zero acres to a conservation practice. As a system of endogenous switching regressions with censored dependent variables, I solve equation **5.6** as a multivariate tobit. Errors are assumed to be distributed jointly normal, but are never observed simultaneously across regimes. Thus, the variance-covariance matrix of errors across equations, Ω_{Acres}, is of a block diagonal form:

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[7] Approximately 40% of Maryland crop farmers are estimated to have received cost share for cover crops (Union of Concerned Scientists, 2012).

[8] I include cost share receipt for no-till and contour-strip farming as regressors, rather than as the factors which determine regime-switching. If switching were based on cast share for all three practices, the interpretation of econometric results would also be unclear: in this case, there would be eight regimes (one for each possible combination of cost sharing), with eight parameter estimates for each right-hand side variable. Therefore, aside from the specific policy relevance of cover crop cost sharing and the small sample size, tractable econometric interpretation is a third reason for implementing a switching regression based only on one cost share award.

$$\Omega_{Acres} = Var\begin{pmatrix} \varepsilon_1^1 \\ \varepsilon_2^1 \\ \varepsilon_3^1 \\ \varepsilon_1^0 \\ \varepsilon_2^0 \\ \varepsilon_3^0 \end{pmatrix} = \begin{pmatrix} \sigma_{\varepsilon 11}^2 & \sigma_{\varepsilon 21\varepsilon 11} & \sigma_{\varepsilon 31\varepsilon 11} & . & . & . \\ \sigma_{\varepsilon 11\varepsilon 21} & \sigma_{\varepsilon 21}^2 & \sigma_{\varepsilon 31\varepsilon 21} & . & . & . \\ \sigma_{\varepsilon 11\varepsilon 31} & \sigma_{\varepsilon 21\varepsilon 31} & \sigma_{\varepsilon 31}^2 & . & . & . \\ . & . & . & \sigma_{\varepsilon 10}^2 & \sigma_{\varepsilon 20\varepsilon 10} & \sigma_{\varepsilon 30\varepsilon 10} \\ . & . & . & \sigma_{\varepsilon 10\varepsilon 20} & \sigma_{\varepsilon 20}^2 & \sigma_{\varepsilon 30\varepsilon 20} \\ . & . & . & \sigma_{\varepsilon 10\varepsilon 30} & \sigma_{\varepsilon 21\varepsilon 31} & \sigma_{\varepsilon 30}^2 \end{pmatrix} \quad (5.7)$$

The off-diagonal elements on the leading block diagonals represent the covariance between conservation acreage decisions for each of the three BMPs. The estimated correlation between a farmer's acreage in BMPs l and k, given that farmer is in regime i, is:

$$\hat{\rho}_{lk}^i = \hat{\sigma}_{\varepsilon li,\varepsilon ki}/\hat{\sigma}_{\varepsilon li}\hat{\sigma}_{\varepsilon ki} \quad (5.8)$$

The system of equations in **5.6** and **5.7** was maximized using the 'mvtobit' package in Stata. Unlike the case of 'mvprobit', Halton Sequences are employed to generate the multivariate normal random draws in order to reduce the computational burden. Halton sequences improve coverage of the domain of integration (Cappellari and Jenkins, 2006), and each sequence is defined by a unique prime number, P. In this case $P = \{2,3,5\}$ were used, respectively, for the equations involving cover crops, contour-strip farming, and no-till. An initial number of sequence elements B are burned within each iteration, in order to reduce correlation of the Halton sequences in each of the three dimensions. Following the advice of Train (2009), B was set to 5 in order to correspond with the largest prime number used in generating the Halton sequences. Fewer random draws R are required with Halton sequences, due to its improved coverage of the domain of integration. Convergence was attained with $R = 20$.

6. Econometric Results

My primary interest in the econometric analysis is to identify the effect of cost sharing for cover crops on the overall mix of conservation practices used on a farm. Before turning to that, however, I will briefly present the marginal effects of the independent variables for the trivariate probit and trivariate tobit. Marginal effects are more informative than coefficient estimates in models with binary or censored dependent variables, as is the case here.

6.1 Cost Share – Trivariate Probit

In the results presented in **Table 3**, the dependent variable is receipt of cost sharing for each of the three practices. Note that 94 of the 451 farmers used in this regression received cost sharing for cover crops, but only 10 and 27 respectively for contour-strip farming and no-till.

The marginal effect of the erosion reduction cost for cover crops is negative and significant, causing a 17.99% reduction in the likelihood of cost sharing. In theory, BMP cost could affect the likelihood of cost sharing in both directions: positively, if higher costs make a farmer more likely to apply for cost sharing; negatively, if higher costs make a farmer less likely to adopt the practice and, therefore, less likely to consider applying for cost sharing (recall that cost sharing is not designed to cover the whole cost, just part of the cost, of implementing conservation practices). The erosion reduction cost does not have a significant influence on cost sharing receipt for contour-strip farming and no-till, which may not be surprising given that most farmers who adopt these practices do so without cost share.

Topography also influences cost sharing receipt, insofar as it affects both the expected conservation benefits as well as a farmer's need to adopt erosion-control practices in the first place, as discussed above. Having a greater share of one's farm moderately sloped (defined as 2 – 8% grade) tends to increase the likelihood of cost share receipt for all three practices. On the other hand, more steeply sloped acreage correlates negatively with cost share receipt. Theoretically, fields of a greater than 8% slope are less suitable for crop production, and are more likely placed in pasture or woods. Thus, the erosion-control practices described here are less applicable in steeply sloped fields.

Distance to the nearest water body serves as a proxy for conservation benefits from the perspective of the regulator-agency. This variable serves as one of the instruments that identify cost sharing receipt, because it only affects a farmer's BMP acreage decisions indirectly through its effect on the likelihood of cost share receipt. As expected, it is negative and significant (in the case of cover crops), or not significant at all: the farther from a water body, the lower the expected conservation benefits, and therefore the lower the likelihood of receiving cost share.

The proportion of income from farming serves as a proxy for the transaction costs of cost share application for the farmer, which is the second variable used to identify cost share receipt with respect to BMP acreage.[9] As expected, the higher proportion of income from farming, the more frequently cost sharing is received, though in the case of contour-strip farming, the relationship is not significant.

Several other independent variables appear in the trivariate probit, including farm size, and farmer education. These variables have the expected influence on cost sharing receipt, or no significant effect at all, with the exception of the negative sign on certain education variables in the contour-strip equation.

6.2 BMP Acreage – Trivariate Tobit

In the results presented in **Table 4** the dependent variable is the share of operating acres on a farm allocated to each of the conservation practices studied. The system of equations is estimated as a multivariate tobit using many of the same independent variables contained in the cost sharing equations, along with cost share receipt itself. Cost sharing receipt for cover crops determines regime-switching in the endogenous switching framework, and cost sharing receipt for contour-strip farming and no-till are included as endogenous right-hand side variables. Inverse Mills ratios from the first stage are included to correct for a farmer self-selection into cost share programs.

[9] A Hausman test was performed to test for a possible weak instrument problem. Results showed no systematic difference in coefficient estimates between a model that included proportion income from farming and one that didn't (p-value=.9907), indicating that the null hypothesis of both models being consistent was not able to be rejected.

The estimated marginal effects of the inverse Mills ratios show that there is indeed self-selection bias in receipt of cost sharing for cover crops, significant at the 1 percent level (0.158). Those who receive cost sharing are likely to place more acreage in that practice, all else equal, but this is only true among *recipients* of cost sharing. On the other hand, the propensity to receive cost sharing for other practices is negatively associated with cover crop acreage. For no-till and contour-strip farming, the propensity to receive cost sharing for cover crops is associated with a reduction in acreage allocated to those practices (among non-recipients only for contour-strip farming acreage). We also see evidence of self-selection bias in no-till: farmers who are likely to receive cost sharing for no-till place more acres in the practice.

The results indicate downward sloping demand, as expected, for each of the BMPs: higher costs (dollars per pound erosion reduced) decrease the acreage share allocated to each practice. However, only for no-till are the results measured precisely enough to be statistically different from zero. For no-till—a practice generally considered profitable for farmers in Maryland—the marginal effect of BMP cost is larger among non-recipients (-0.3807%) in comparison to recipients of cover crop cost share (-0.1841%).

The cross-price marginal effects between cover crops and no-till indicate complementarity, for the economic and agronomic reasons already discussed (approximately a 15% reduction in acreage share due to a $1 / pound increase in the cost of the other practice). On the other hand, patterns of substitution are implied between no-till and contour-strip farming, among both recipients and non-recipients or cost share (a $1 / pound increase in the cost of no-till increases the a farm's acreage share in contour-strip farming by about 78%, while a $1 / pound increase in contour-strip farming increases by 21% the acreage share in no-till). Finally, there was in general a lack of statistical significance in the cross-price marginal effects between cover crops and contour-strip farming.[10]

The marginal effects of the cost sharing indicators show little statistically significant effect of contour-strip and no-till cost sharing on acreage of each practice, though this does not necessarily mean that no effect exists. (Note that the inclusion of the inverse Mills ratios makes these endogenous explanatory variables consistent.) No-till cost share results in a 38.58% increase in the acreage share devoted to no-till, among farmers not receiving cost sharing for cover crops. A smaller effect was measured among farmers receiving cost sharing for cover crops (0.1016 increase), though this was not found to be statistically different from zero. These results are qualitatively similar to that of Mezzatesta et al. (2013), for whom a treatment effect of 0.1499 was identified for conservation tillage cost share among farmers in Ohio. At the same time, statistically significant treatment effects were also identified across BMPs, as no-till cost sharing is associated with 52% and 25% increase in acreage share in cover crops (among recipients and non-recipients of cover crop cost share, respectively). Along with the cross-price marginal effects between these two BMPs, discussed above, this further indicates complementarity

[10] Symmetry of the second derivatives in a demand equation (Young's theorem) would suggest that the cross-price elasticities should be equal – if all that matters to the farmer is the marginal cost of BMP implementation, there are no output effects, and the marginal cost per acre is equal. For this reason, the cross-price coefficients were constrained to be equal when maximizing the system of equations **5.6** and **5.7,** the results of which are described in **Table 4**. While the cross-price coefficients are equal, the marginal effects are slightly different due to the equation that converts coefficient estimates to marginal effects in a censored regression equation (though the sign always remains the same).

between cover crops and no-till. The indirect treatment effects of cover crop cost sharing on other BMPs will be discussed in **Section 6.3.**

Finally, several other controls related to farm and farmer characteristics appear on the right hand side of the trivariate tobit. For the reasons discussed in **Section 5.2**, many of these variables were constrained to be equal across regimes. The controls have the expected effect on acreage shares, or no effect at all, with the exception of the positive sign on the proportion of operating acres rented in the no-till equation. Here it is important to keep in mind that many contemporary tenant farmers are neither indigent nor landless, but are often large, successful farmers who have outgrown their property.

6.3 Treatment effects of cost sharing for cover crops

It is now possible to turn to identifying the effect of cost sharing for cover crops on the overall mix of conservation practices used on a farm, displayed in **Table 5**.

An advantage of the switching regression, along with its generality, is that it allows for calculation of not only an average treatment effect of cost sharing on the treated subjects (*ATT*), but also an expected treatment effect of cost share on those subjects not currently treated (average treatment effect on the untreated, or *ATU)* (cf. Heckman & Vyclatil, 2007). While the *ATT* is the most relevant tool for program evaluation, the *ATU* is arguably more relevant for policy forecasting, since it represents the expected effect of extending cost share beyond the population of those currently receiving it.

The treatment effects are initially calculated for each farmer j and BMP m. Letting J^1 and J^0 represent the set of treated and untreated farmers, and the other notation as in equations **5.1** and **5.6**, then

$$\begin{aligned} \widehat{TET}_{jm} &= E\left(a_{jm}^1 \,|CS_{j1} = 1, X_{jm}, Z_{jm}\right) - E\left(a_{jm}^0 \,|CS_{j1} = 1, X_{jm}, Z_{jm}\right),\ j\epsilon\, J^1, \\ \widehat{TEU}_{jm} &= E\left(a_{jm}^1 \,|CS_{j1} = 0, X_{jm}, Z_{jm}\right) - E\left(a_{jm}^0 \,|CS_{j1} = 0, X_{jm}, Z_{jm}\right),\ j\epsilon\, J^0. \end{aligned} \tag{6.1}$$

These treatment effects are initially expressed in terms of changes in *acreage shares*, as in equation **5.6**, and are converted to acres by multiplying the expected treatment effect for each farmer by the operating acres on that farm (A_j). The average treatment effects for each BMP then, as shown in **Table 5**, are weighted averages of the estimated treatment effects for each farmer. That is,

$$\begin{aligned} \widehat{ATT}_m &= \textstyle\sum_{j=1}^{J^1} w_j\left(\widehat{TET}_{jm} \cdot A_j\right), \\ \widehat{ATU}_m &= \textstyle\sum_{j=1}^{J^0} w_j\left(\widehat{TEU}_{jm} \cdot A_j\right), \\ &\text{where } \textstyle\sum_{j=1}^{J^1} w_j = 1 \\ &\text{where } \textstyle\sum_{j=1}^{J^0} w_j = 1 \end{aligned} \tag{6.2}$$

An ATT of 225 acres indicates that farmers who received cost sharing for cover crops allocated, on average, 225 more acres to cover crops than they would have otherwise. This is significant at the 99%

level.[11] The ATU of 16.8 suggests that fewer gains are possible by extending cover crop cost sharing to currently untreated subjects.

Receipt of cost sharing for cover crops also increases the farmer's land in no-till by 61.9 acres, and would have an expected positive effect on no-till acreage among untreated subject as well, albeit smaller (2.5). This may be due to the economic and agronomic complementarity between these two practices discussed earlier: cover crops contribute to the efficiency of conservation tillage systems by adding increased organic matter to the soil, and stimulating soil biological activity (SARE 2012); and no-till may improve the economic efficiency of cover crop use, as no-till reduces the planting time required in the already-busy fall farming season.

On the other hand, receipt of cost sharing for cover crops appears to reduce the acres in contour-strip farming by 76.3 acres among treated farmers. This may be due to the indirect effect of cover crops on no-till, and the agronomic substitution between no-till and contour-strip farming as evidenced by the Revised Universal Soil Loss Equation: sloped fields become significantly less vulnerable to erosion in no-till systems, and so a farmer faces diminishing returns in terms of erosion-reduction. This may allow farmers to avoid the costs involved in contour-strip farming once they have adopted no-till.

In summary, the heavy subsidies for cover crops in Maryland increased the use of cover crops among treated farmers (225 acres), and indirectly increased the use of no-till (62 acres); however, they indirectly decreased the use of contour-strip farming (-76 acres). Among untreated farmers, on the other hand, subsidies for cover crops are projected to have unambiguously positive effects. Acreage in cover crops, no-till and contour-strip farming would all be expected to increase (albeit to a smaller degree among cover crops and no-till) as a result of extending cost share to those not currently receiving the subsidy.

Because certain regressors were set to be equal across regimes, I estimate the ATT and ATU for a version of the model in which all independent variables are switching as a robustness check. These results are shown in column [2] of **Table 5**. The estimated effects are qualitatively the same, but the magnitudes are somewhat different. In particular, the ATT for cover crops and contour-strip farming is smaller in absolute value.

7. Effect of Cost Share on Nitrogen and Phosphorus in the Chesapeake Bay

7.1 Pollution

The question then remains: what does this mean for non-point source pollution in the Chesapeake Bay? First, **Table 6** shows the estimated effect of cost sharing for cover crops on pollution levels—nitrogen (N)

[11] The ATT and ATU of cover crops in terms of change in *acreage shares* were 0.255 and 0.029, respectively. This ATT is of a similar magnitude to that found in previous surveys of farmers in Ohio (0.237) (Mezzatesta et al. 2013) and somewhat higher than that previously found by Lichtenberg & Smith-Ramirez for cover crops in Maryland (0.081), though different methodologies were used in these studies.

and phosphorus (P)—in the Bay. Estimates are broken down by major river basin in Maryland (a map of river basins is shown in **Figure 3**).

Pollution reduction estimates are shown for representative treated and untreated farms in the UMD survey. The representative treated farm has 233 acres in cover crops, of which 225 are due to the treatment effect. Change in pollutant p (where $p = \{\mathrm{N}, \mathrm{P}\}$), due to adoption of BMP m, in river segment s is calculated as:

$$\text{Direct: } \Delta_{ps} = (\widehat{ATT}_1 \cdot \bar{z}_{ps} \cdot \theta_{1ps}) \cdot \delta_{ps},\ \mathrm{s} = 1 \ldots S \text{ river segments,}$$
$$\text{Indirect: } \Delta_{ps} = \textstyle\sum_{m=1}^{3} (\widehat{ATT}_m \cdot \bar{z}_{ps} \cdot \theta_{mps}) \cdot \delta_{ps},\ \mathrm{s} = 1 \ldots S \text{ river segments.} \tag{7.1}$$

Here, $\bar{z}_s$ is the pollution load per acre from cropland within each river segment in Maryland; θ_{mps} is the pollution reduction efficiency of each BMP (and $m = 1$ refers to cover crops); and δ_{ps} is the delivery ratio of nitrogen or phosphorus from each river segment to the Chesapeake Bay. Change in pollution within each major river basin, as shown in **Table 6**, is then calculated as the average of Δ_{ps} across all river segments in that basin (weighted by acreage).[12]

As **Table 6** shows, there is a substantial reduction in both pounds of nitrogen and phosphorus reaching the Bay due to the treatment effect on cover crops among treated farmers (1,935 lbs. and 43.7 lbs., respectively, on the Eastern Shore). However, this effect is partly mitigated by the indirect effect on the other BMPs. For phosphorus, the difference between the direct and indirect effect is sometimes quite large: abatement declines from 43.7 to only 23.9 pounds of P reduction on a representative treated farm on the Eastern Shore, nearly a 40% decline.[13]

On the right-hand side of **Table 6** the same calculations are performed for representative untreated farms in each river basin. On average, untreated farms are much smaller, with only about 5 acres in cover crops, of which 16.8 additional acres are expected with cost share. In this case, there are indirect benefits to extending cost share to this group of farmers. For phosphorus, once again, the effect is proportionally large: expected phosphorus reduction per farm increases from 3.5 to 5.6 lbs on the Eastern Shore, and 3.6 to 7.4 lbs. in the Potomac River Basin.

However, it is important to keep in mind the magnitude of pollution reduction from agriculture targeted by the TMDL goals. **Table 7** shows the estimated 2013 pollution loads from agriculture in each major river basin, along with the 2025 TMDL goals. Approximately 1.39 million pounds of nitrogen reduction from agriculture are targeted for the Eastern Shore, and 77,000 pounds of phosphorus reduction. Using the data from **Table 6**, achieving this goal via cost share for cover crops alone would entail extending

[12] Columns [1] and [4] of Table 6 are based on the "direct" version of Δ_{ps}, while columns [3] and [6] are based on the "indirect" version.

[13] Mechanically, the indirect effect on phosphorus runoff is larger than that on nitrogen due to the fact that contour-strip farming—which is observed to be crowded out by the adoption of cover crops and no-till—is more effective at reducing phosphorus runoff than nitrogen.

cost share to an additional 8,000 to 14,000 of the representative untreated farms (for nitrogen and phosphorus goals, respectively). To put this in perspective, the 2012 US Census of Agriculture estimated that there are 12,256 farms in Maryland, which suggests that the TMDL goals for agriculture could not be achieved by cost sharing for cover crops alone, even after accounting for indirect effects.

7.2 Cost Effectiveness

Finally, what does this mean for the cost effectiveness of cover crop cost sharing? Even if the TMDL goals are unlikely to be achieved via cover crop cost sharing alone, it remains to be seen how the indirect effects of cost sharing—as estimated in this study—influence the cost effectiveness of abatement. Is cost sharing truly cost effective in comparison to other methods?

Table 8 shows the dollars per pound of nitrogen and phosphorus reduction, based upon a representative cost share award of $65 per acre.[14] After considering indirect effects, nitrogen reduction becomes slightly more expensive among the treated farmers: increasing from $6.84 to $7.06 per pound in the Eastern Shore. The cost of phosphorus reduction increases significantly: $302 to over $550 per pound of phosphorus reduced in the Eastern Shore. Considering all five major river basins, the marginal abatement cost of phosphorus increases by between 35 and 80% after accounting for indirect effects.

Among untreated farmers, however, the cost effectiveness of phosphorus reduction is greatly improved after accounting for the indirect effects of cost share for cover crops on other BMPs. Again using the example of the Eastern Shore, the cost per pound reduced goes from $424 per pound to about $263. Across all five major river basins, there is between a 38 and 55% improvement in cost effectiveness. The cost effectiveness also improves, albeit by a smaller percentage, for nitrogen reduction.[15]

Table 9 compares these cost effectiveness estimates to those from other recent studies on the cost of reducing phosphorus and nitrogen loads from agriculture in the Chesapeake Bay watershed. In comparison, the costs estimated here for treated farmers show that the cost of reducing nitrogen was relatively low both before and after accounting for indirect effects. Among untreated farmers, the prospect of extending cost sharing is greatly improved when considering indirect effects. For this group of farmers, nitrogen and phosphorus reduction become relatively inexpensive when considering the positive spillovers on the mix of conservation practices in use on a farm, as identified in this study. Thus, extending cost sharing to the currently untreated subjects – despite their relatively small magnitude in terms of pounds of reduction – is a potentially low-hanging fruit for cost share programs.

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[14] $65 per acre is the award for cover crops planted in rye by October 1st. Note that nitrogen and phosphorus reduction efficiencies for cover crops themselves vary by crop type and date planted, as discussed in **footnote 4**. The pollution reduction estimates shown in **Table 6** use the reduction efficiency for a cover crop of rye planted early (by October 1st).

[15] These cost effectiveness estimates account for the Chesapeake Bay Program's modeled estimates of the fraction of nitrogen and phosphorus actually delivered to the Bay in a given year. It is unclear if these estimates adequately account for the long residence time of nitrates in groundwater (cf. USGS, 2003).

8. Conclusion

With the increased scrutiny of agricultural non-point source pollution, policymakers are interested in understanding the tradeoff between costs of agricultural conservation and measurable improvements in water quality downstream. But the causal effect of cost sharing on water quality is difficult to identify. Along with the problems of self-selection into cost sharing programs, and the difficulties in measuring how changes in farmer behavior affect NPS pollution, the existence of correlation and substitution among various conservation practices and land uses makes the econometric evaluation of cost sharing programs complex.

This study has estimated the effect of cost sharing for cover crops on the acres of three erosion-control practices—cover crops, contour-strip farming, and no-till—using a survey of Maryland farmers; and it has used data from the US EPA's *Chesapeake Bay Program* to relate these effects of cost sharing to water quality benefits. The primary contribution of this study is to analyze both the direct and indirect effects cost sharing for cover crops – a heavily subsidized practice in the study region – on the overall mix of erosion-control practices used on a farm. I find that the heavy subsidies for cover crops in Maryland increased the use of cover crops among treated farmers (225 acres), and indirectly increased the use of no-till (62 acres); however, they indirectly decreased the use of contour-strip farming (-76 acres). The substitution away from contour-strip farming decreases the net abatement of nitrogen and phosphorus due to cost sharing in most of Maryland's major river basins, and increases the cost per pound of phosphorus reduced by between 35 and 80%.

Among untreated farmers, on the other hand, subsidies for cover crops are projected to have unambiguously positive effects. Acreage in cover crops, no-till and contour-strip farming would all be expected to increase as a result of extending cost share to those not currently receiving the subsidy, albeit to a smaller degree given the relatively smaller size of the untreated farms (by 22, 2.5, and 2.1 acres, respectively). I estimate that the indirect benefit of cover crop cost sharing on other BMPs decreases the cost per pound of phosphorus abatement between 38 and 55% for the group of untreated farmers.

This study is limited by several factors. First, the policy implications regarding cost effectiveness are sketched out in a very basic and preliminary fashion, for purposes of illustrating the importance of indirect effects and correlation in practice adoption. Future research, along the lines of Wainger et al. (2013), may combine the estimation of indirect effects of cost share subsidies with various policy scenarios and cost assumptions.

Second, from a practical standpoint, farmers may "intensify" an erosion-control BMP on a given acre of land (e.g. planting cover crops earlier, more densely; continuous no-till vs. a rotation of no-till and conventional tillage methods; etc.). In this regard, BMP costs and pollution reduction efficiencies all become functions of the intensity of BMP use. While data limitations prevented the consideration of the intensity of BMP use, this limitation is especially important to bear in mind when translating these results to policy implications. Third, the lengthy residence time of nitrates in groundwater in the

Chesapeake Bay region (USGS 2003) implies that not all the benefits from changes in farmer behavior will immediately be observed in the Bay. Finally, several other conservation practices commonly used in Maryland play a prominent role in a farmer's land use decisions—including riparian buffers and grass-lined waterways. However, the reported acreages of these practices in the farmer survey are not comparable with those of cover crops, no-till and contour-strip farming, which made it difficult to obtain reasonable results when considering these other practices in a simultaneous estimation framework.

These empirical limitations point to several possibilities for future research. Data refinements may allow for empirical estimation that captures a wider range of practices and more closely aligns with on-the-ground conditions. Moreover, the estimated distribution of treatment effects on both treated and untreated farmers may allow for policy simulations that go beyond the current structure of cost sharing programs, by considering other methods of abatement of non-point source pollution from agriculture such as water quality trading.

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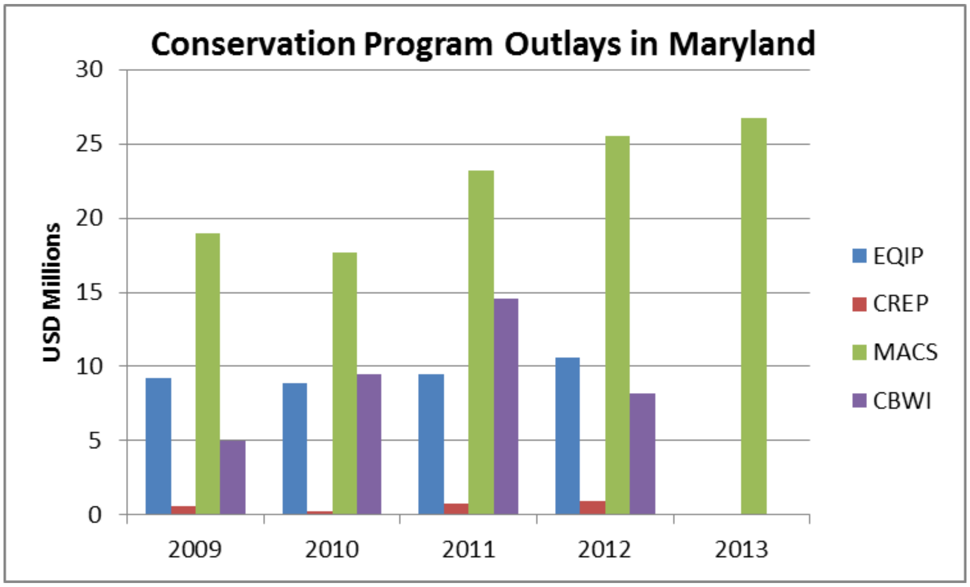
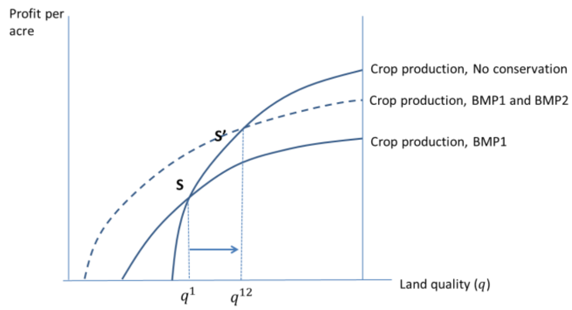
Figure 1



Notes: CBWI is the Chesapeake Bay Watershed Initiative, administered through the USDA, NRCS. It primarily funds cover crops, conservation tillage, strip farming, and nutrient management plans (NMPs). MACS funds are primarily directed to cover crops, but also livestock fencing, NMPs, and 27 other qualifying practices. EQIP funds 80 qualifying practices, particularly manure management, nutrient management, and wildlife habitat enhancement. CREP funds practices which take environmentally sensitive land out of production, including riparian buffers, wetlands, and highly erodible land.

Figure 2

Complementarity in fixed costs



Complementarity in efficiency

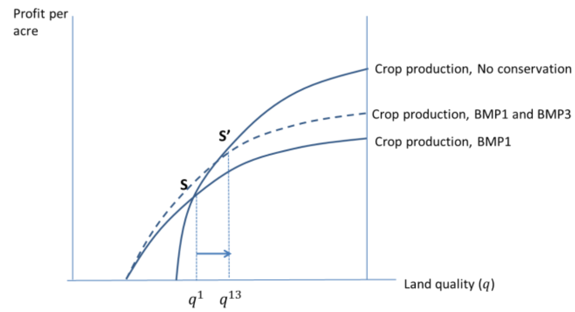


Figure 3

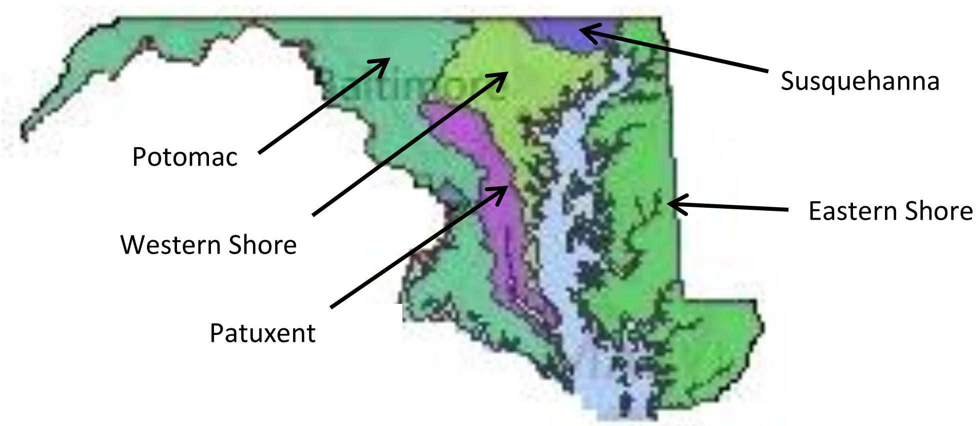

Susquehanna
Potomac
Eastern Shore
Western Shore
Patuxent

Table 1

BMP Adoption, Cost Share Receipt, and Percent Acres Adopted by Practice

Practice type	Number of farms			Average Percent Acres	
	No Adoption	Self-financed adoption	Adoption with cost share	Self-financed adoption	Adoption with cost share
	[1]	[2]	[3]	[4]	[5]
Cover crops	301	56	94	20.1%	27.1%
Conservation tillage	205	219	27	46.0%	40.7%
Contour farming	392	54	5	31.6%	26.2%
Strip farming	378	68	5	29.4%	38.8%

Table 2

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Farmer age	510	62.49	12.6	22	92
Graduated high school (1=yes; 0=no)	517	0.85	0.4	0	1
Highest level of education attained (Graduated high school)	517	0.42	0.5	0	1
(Some college)	517	0.12	0.3	0	1
(Completed comm. college)	517	0.05	0.2	0	1
(Bachelor's degree)	517	0.16	0.4	0	1
(Master's or Ph.D.)	517	0.09	0.3	0	1
Operating acres (thousands)	523	0.43	0.8	0.0001	9.78
Animal Units (thousands)	523	0.29	1.4	0	20.64
Proportion acres moderately sloped (2-8% grade)	515	0.42	0.4	0	1
Proportion acres steeply sloped (>8% grade)	517	0.08	0.2	0	1
Proportion operating acres rented	520	0.24	0.3	0	1
50 or more acres in corn, soybeans, or small grains (=1 or 0)	523	0.46	0.5	0	1
Distance to the nearest water body (miles)	501	0.55	2.1	0	35
Proportion income from farming	500	0.48	0.4	0	1
Erosion reduction cost ($ / ton reduced) (Cover crops)	505	43.09	32.2	6.67	138.17
(Contour-strip farming) ($ / ton)	505	38.28	31.6	5.11	135.53
(No-till) ($ / ton)	518	18.58	12.9	3.91	48.32
Cost share receipt (1=yes; 0=no) (Cover crops)	493	0.19	0.4	0.00	1.00
(Contour-strip farming)	497	0.02	0.1	0.00	1.00
(No-till)	476	0.05	0.2	0.00	1.00
Proportion acres in BMP (Cover crops)	493	0.08	0.2	0.00	1.00
(Contour-strip farming)	497	0.08	0.3	0.00	2.00
(No-till)	476	0.25	0.4	0.00	1.00

Table 3

Estimated marginal effects on cost share receipt
Multivariate Probit - Full Correlation

	Cost Share		
	Cover Crops (1=yes, 0=no)	Contour-Strip (1=yes, 0=no)	No-till (1=yes, 0=no)
Erosion reduction cost (Cover crops)	-0.1799**	-0.1926	-0.9294***
($ per lb. erosion reduced)	(0.13)	(0.26)	(0.49)
(Contour-strip farming) ($ / lb.)	0.2292***	0.1043	0.8672***
	(0.14)	(0.19)	(0.29)
(No-till) ($ / lb.)	0.3504	0.0961	-0.1053
	(0.48)	(0.20)	(0.50)
Proportion acres moderately sloped	0.0521*	0.029***	0.0646***
(2-8% grade)	(0.04)	(0.02)	(0.02)
Proportion acres steeply sloped	-0.0182	-0.0377	-0.0264
(> 8% grade)	(0.06)	(0.03)	(0.05)
Operating acres (thousands)	0.0647***	0.0056	-0.0091
	(0.03)	(0.00)	(0.01)
Highest level of education attained	0.0785***	0.0046	0.0939***
(Graduated high school)	(0.04)	(0.01)	(0.03)
(Some college)	0.0672**	-0.0047	0.0865***
	(0.04)	(0.02)	(0.04)
(Completed comm. college)	-0.0295	-0.1283***	0.1173***
	(0.05)	(0.02)	(0.05)
(Bachelor's degree)	0.144***	0.0055	0.1071***
	(0.05)	(0.02)	(0.04)
(Master's or Ph.D.)	0.0676*	-0.1243***	0.1201***
	(0.05)	(0.01)	(0.04)
Distance to the nearest water body	-0.0202***	-0.0001	-0.0014
(miles)	(0.01)	(0.00)	(0.01)
Proportion income from farming	0.1505***	0.01	0.0476***
	(0.03)	(0.01)	(0.02)
Observations	451	451	451

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4

Estimated marginal effects on share of operating acreage in conservation practices

Multivariate Tobit - Full Correlation

	Acreage share - *Switching based on cover crop cost share*					
	Cover crop		Contour-strip farming		No-till	
	(Cost Share = 1)	(Cost Share = 0)	(Cost Share = 1)	(Cost Share = 0)	(Cost Share = 1)	(Cost Share = 0)
Lambda (covariance w/ cover crop	0.158***	0.013	0.1043	-0.0352	-0.0328	-0.2146***
cost share)	(0.06)	(0.02)	(0.10)	(0.04)	(0.06)	(0.08)
Lambda (covariance w/ contour-strip	-0.9592***	-0.3013*	0.2472	0.2189	0.603	-0.1118
cost share)	(0.45)	(0.18)	(0.36)	(0.18)	(0.68)	(0.49)
Lambda (covariance w/ no-till	-0.2794***	0.0017	0.0939	-0.1202	0.0342	0.2297***
cost share)	(0.16)	(0.06)	(0.28)	(0.20)	(0.23)	(0.13)
Erosion reduction cost (Cover crops)	-0.1052	-0.2028	-0.1058	-0.3538	-0.1519***	-0.0331
($ per lb. erosion reduced)	(0.20)	(0.60)	(0.08)	(0.32)	(0.76)	(0.67)
(Contour-strip farming) ($ / lb.)	-0.2681*	-0.3923	-0.2839	-0.1125	0.2121***	0.1556***
	(0.21)	(0.44)	(0.70)	(0.40)	(0.08)	(0.05)
(No-till) ($ / lb.)	-0.1423***	-0.1269	0.7842***	0.5383*	-0.1841**	-0.3807***
	(0.07)	(0.26)	(0.35)	(0.38)	(0.13)	(0.13)
Contour-strip cost share (1=yes; 0=no)	0.2125	0.0438	0.2236	0.3533	-1.3662	0.2641
	(0.20)	(0.38)	(0.86)	(0.38)	(1.58)	(1.11)
No-till cost share (1=yes; 0=no)	0.5245**	0.251*	-0.0845	0.1835	0.1016	0.3858*
	(0.33)	(0.16)	(0.61)	(0.38)	(0.49)	(0.28)
Proportion acres moderately sloped	0.08		0.0817		-0.0129	
(2-8% grade)	(0.07)		(0.12)		(0.13)	
Moderately sloped-squared	-0.0012**		-0.0011		0.0011	
	(0.00)		(0.00)		(0.00)	
Proportion acres steeply sloped	0.7731	0.2727	0.361		0.4306***	
(> 8% grade)	(0.72)	(0.19)	(0.45)		(0.24)	
Steeply sloped-squared	-0.0124	-0.0226***	-0.0059		-0.0052**	
	(0.02)	(0.01)	(0.01)		(0.00)	
Proportion operating acres rented	-0.0165		0.0221		0.091***	
	(0.02)		(0.04)		(0.03)	
50 or more acres in corn, soybeans or	0.0205		0.0798		0.1794***	
small grains (= 1 or 0)	(0.02)		(0.07)		(0.03)	
Animal units (thousands)	0.0053***		-0.0213		-0.0002	
	(0.00)		(0.02)		(0.00)	
Operating acres (thousands)	-0.015**		0.0073		0.0182	-0.1269***
	(0.01)		(0.02)		(0.04)	(0.03)
Farmer age	-0.001**		-0.0003		-0.0002	
	(0.00)		(0.00)		(0.00)	
Graduated high school	-0.0081	-0.0245*	-0.0273		-0.0005	
(1=yes; 0=no)	(0.07)	(0.02)	(0.05)		(0.04)	
Observations	94	348	94	348	94	348

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5

Estimated treatment effect of cost share award on conservation acres
Expected effect on treated (ATT) vs. untreated (ATU) subjects

	Switching where warranted		Switching of all parameters^	
	[1]		[2]	
Effect of cover crop cost share on acres of cover crops				
ATT:	225.4***	(6.9)	192.2***	(7.7)
ATU:	16.8**	(7.3)	22.0*	(11.6)
Effect of cover crop cost share on acres of contour-strip farming				
ATT:	-76.3***	(19.3)	-55.6*	(29.0)
ATU:	5.6*	(2.7)	2.5*	(1.1)
Effect of cover crop cost share on acres of no-till				
ATT:	61.9***	(3.0)	98.6***	(2.3)
ATU:	2.5*	(1.4)	2.1*	(1.2)

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
^BMP acreage equations solved independently, not in a system.

Table 6

Estimated effect of cost share award on non-point source agricultural pollution in Chesapeake Bay

		Pounds of N and P reduction in the Bay due to cover crop cost share award					
		ATT			ATU		
		Cover crops	Related BMPs	Overall effect	Cover crops	Related BMPs	Overall effect
		[1]	[2]	[3]	[4]	[5]	[6]
Eastern Shore	Nitrogen	1,935	-62	1,873	154	19	174
	Phosphorus	43.7	-19.8	23.9	3.5	2.1	5.6
Patux-ent	Nitrogen	1,412	-65	1,347	113	25	137
	Phosphorus	45.1	-11.5	33.6	3.6	4.3	7.9
Poto-mac	Nitrogen	1,867	-28	1,839	149	26	175
	Phosphorus	45.4	-14.2	31.2	3.6	3.7	7.4
Susque-hanna	Nitrogen	2,398	-17	2,381	191	39	231
	Phosphorus	27.0	-10.0	17.1	2.2	1.9	4.0
Western Shore	Nitrogen	1,416	-95	1,321	113	29	142
	Phosphorus	36.1	-9.8	26.2	2.9	3.3	6.2

[1] and [4]: Load reduction due to the direct effect of cover crop cost share on farmers' use of cover crops.
[2] and [5]: Load reduction (or gain) due to the indirect efect of cover crop cost share on farmers' use of other related BMPs.
[3] and [6]: Calculated as [1] + [2] and [4] + [5], respectively.
Ratios of load delivered to Bay from Cheapeake Bay Program's Phase 5.3 watershed model.

Table 7

TMDL Progress and Targets for Agriculture in Maryland, by Major River Basin

	Nitrogen *(thousands of lbs. / year)*			Phosphorus *(thousands of lbs. / year)*		
	2013 Progress	2025 Target	Reduction required	2013 Progress	2025 Target	Reduction required
Eastern shore	8,825	7,435	1,390	860	783	77
Patuxent	472	429	43	70	63	6
Potomac	6,146	5,741	405	475	456	19
Susquehanna	717	651	66	42	37	5
Western shore	661	594	67	59	54	5
Total	**16,821**	**14,850**	**1,971**	**1,507**	**1,395**	**112**

Source: Based on data from ChesapeakeStat (http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=2)

Table 8

Cost effectiveness of cover crop cost share, with and without indirect effects of cost share

		Representative treated farm (ATT)		Representative untreated farm (ATU)	
		Direct	Indirect	Direct	Indirect
East. Shore	Nitrogen ($ / lb. reduced)	$6.84	$7.06	$9.59	$8.52
	Phosphorus ($ / lb. reduced)	$302.49	$552.98	$424.38	$262.94
Patux ent	Nitrogen ($ / lb. reduced)	$9.37	$9.79	$13.14	$10.79
	Phosphorus ($ / lb. reduced)	$293.37	$394.04	$411.59	$187.36
Poto mac	Nitrogen ($ / lb. reduced)	$7.09	$7.20	$9.95	$8.49
	Phosphorus ($ / lb. reduced)	$291.56	$423.90	$409.05	$201.56
Susq ueh.	Nitrogen ($ / lb. reduced)	$5.52	$5.56	$7.74	$6.42
	Phosphorus ($ / lb. reduced)	$489.33	$775.64	$686.52	$368.81
West. Shore	Nitrogen ($ / lb. reduced)	$9.34	$9.93	$13.11	$10.47
	Phosphorus ($ / lb. reduced)	$366.60	$504.07	$514.33	$239.68

Cost share of **$65 per acre** for cover crop planted in rye by October 1st.
Expected cover crop acreage on treated farms is 233, of which 225 is due to the treatment effect.
Expected cover crop acreage on untreated farms is 5, of which 16.8 add'l would be expected with cost share.

Table 9

Comparison of studies on cost effectiveness of pollution reduction in the Chesapeake Bay watershed

Authors	Publication	Year	Dollars per pound reduced		Scenario	Location	Data source
			Nitrogen	Phosphorus			
Bosch et al.	ARER	2013	$6 to $14	-	Practice incentive for cover crops	Maryland (coastal and noncoastal plain)	Calibrated with USDA county-level data and MD grain marketing budgets
Wieland	White Paper	2010	$4 to $14	-	Practice incentive for cover crops	Maryland	Annual MACS program data
Wainger et al.	ARER	2013	$3.43 to $55.34	$22.50 to $368.47	Various scenarios to achieve TMDL goals (taking land out of agricultural production, variable credit trading ratios, etc.)	Potomac basin	CBP Phase 5.3 Watershed Model; implementation costs of BMPs from several sources
Van Houtven et al.	Chesapeake Bay Commission	2012	$5 to $50	$300 to $1300	Reduction from significant point sources (sigPS). Achieves 5.1M pounds of N reduction; 252k pounds of P reduction.	Maryland	Uses implementation costs of cover crops from Wieland et al. (2009)

Appendix 1 – Description of the BMPs studied

Many farmers across the United States implement conservation practices—called "best management practices" (BMPs)—which generate private benefits for farmers by reducing soil loss, improving agricultural efficiency, and maintaining the productivity of a farm for future generations. However, many of these practices also generate social benefits in the form of reduced nutrient and sediment runoff. The BMPs analyzed in this study will be a group of erosion-control practices that provide this type of private and social benefit. The practices are cover crops, conservation tillage, contour farming and strip farming.

Cover Crops

Description: Cover crops are planted on working fields of cropland during the off-season, when many fields are left bare and are therefore highly vulnerable to wind, rain, and snowmelt erosion. It is a traditional practice used by farmers to protect and build soil from the late fall to the early spring, as well as for livestock grazing during these months. The most typical types of cover crops are grasses like rye, or small grains like barley or wheat. Along with holding soil in place, cover crops reduce the leaching of nitrogen from farm fields, thereby helping to address problems such as groundwater contamination and hypoxic "dead zones" downstream from the farm.

Barriers to adoption: Despite the clear benefits of cover crops, adoption is quite low in many places. A survey of farmers in the Corn Belt found that only 8 percent had used cover crops in the previous year. Why are many farmers unable to adopt this practice? One reason cited by farmers is the difficulty of getting out to the fields to re-plant in the fall, especially when conditions are wet. Other constraints to cover crop adoption include the direct costs (seed, fuel, additional time required, etc.), indirect costs (potential impact on crop insurance availability, constraints imposed on the growing season of cash crops), and the potential of delayed returns on investment (Union of Concerned Scientists, 2012).

Incentives and policy debate: Cover crops are highly subsidized in Maryland. According to independent estimates, 60% of farmers in Maryland used cover crops over the 2012-2013 winter season (Union of Concerned Scientists, 2012). This was in large part due to the aggressive incentive programs spearheaded by *MACS* and the *CBWI*. These programs come at a cost. In 2013, *MACS* spent $20.8 million on cover crops. Maryland farmers who plant cover crops earlier in the fall are currently eligible for subsidies of up to $100 per acre, far exceeding recent estimates of the direct costs of cover crop adoption (cf. Wieland et al. 2010). On the other hand, farmers who harvest and sell their small grain cover crops in the spring ("commodity cover crops") are eligible for a much smaller subsidy of up to $35 per acre. Since cover crops are an annual practice, as opposed to a one-time investment, these subsidies are offered on a yearly basis. Other competing uses for these funds include tax credits for the retrofitting of older sewage treatment plants (Hansen et al., 2008), the subsidization of riparian buffers or other BMPs throughout the Chesapeake Bay watershed (Lynch et al., 2006), as well as the development of nutrient trading or payment for measurable environment services to achieve water quality goals (Shabman et al. 2011). The relevant questions for policymakers are the following: which investment of public funds is the most cost effective (which includes the question of targeting, and alternative policies such as nutrient trading for water quality); and what is the magnitude of water quality benefits achieved given this investment.

Conservation tillage

Description: Conservation tillage is any method of soil cultivation that leaves the previous year's crop residue (such as corn stalks or fodder) on fields before and after planting the next crop, to reduce soil erosion and runoff. At least 30% of the soil residue must be covered after planting the next crop. There are several types of conservation tillage, some of which forego traditional tillage entirely and leave 70% of residue or more. For example, no-till (and strip-till) involves planting the crop directly into residue that hasn't been tilled at all (or has been tilled only in narrow strips with the rest of the field untilled). Ridge-till involves planting row crops on permanent ridges about 4-6 inches high. Mulch-till is any other conservation tillage system that leaves at least one-third of the soil surface covered with crop residue. In addition to reducing soil erosion, conservation tillage improves soil quality over time by adding organic matter as crop residue decomposes, creating an open and undisturbed soil structure.

Barriers to adoption: Conservation tillage significantly saves a farmer's time and fuel costs, since fewer tractor hours are required during planting season. However, it entails increased herbicide costs to knock-down any plant growth that occurred during the off-season. More importantly, it involves the use of newer technologies in planting equipment (which are often rented from other farmer's as "custom planting", rather than purchased directly) and for older farmers requires a change in the received understandings of the optimal way to incorporate organic matter back into the soil. Traditionally, it was believed best to turn organic matter back under the soil through plowing.

Incentives and policy debate: Since it is generally considered profitable for farmers to adopt conservation tillage, due to the significant savings in fuel and time, fewer incentives are available for farmers to adopt these methods. *EQIP* and *CBWI* provide an incentive of up to $25 per acre for the first three years in which conservation tillage is adopted. However, since conservation tillage is fast becoming a conventional practice among crop farmers, it is unclear if farmers who apply for this subsidy would adopt conservation tillage even without it. Previous research has shown the additional benefit gained for cost sharing for this practice is very low, both in rural Ohio (Mezzatesta et al. 2013) and across the United States (Claassen and Duquette. 2012).

Contour farming and Strip farming

Description: Contour farming and strip farming are two related methods of controlling soil loss from working cropland. Contour farming is the planting of rows along the contours of a field, perpendicular to the prevailing slope. This reduces soil loss due to wind and rain once the row crops are sufficiently established. Strip farming involves the establishment of perennial grass or hay fields in strips between fields of cash crops. The strips are normally located downslope from the fields of cash crops, in order to prevent soil loss from the farm though not the field of cash crops. Contour farming and strip farming are not mutually exclusive, and in fact have been shown to work in a complementary fashion at reducing soil loss (cf. RUSLE 2013).

Barriers to entry: Both contour farming and strip farming are frequently practiced by farmers who grow cash crops on sloped fields. Prior to the 1930s, straight-line planting in rows parallel to field boundaries and regardless of slopes was the prevalent method of cropping in the United States, but efforts by the U.S. Soil Conservation Service to promote contouring as an essential part of erosion control led to its widespread adoption (USDA 2012). No additional direct costs are required to practice contour farming, but only additional care, time and attention in order to plow or plant rows according to the slope of a field. Strip farming increases the effectiveness of contour farming, but requires farmers to forego the potential profit earned by planting more valuable cash crops—as opposed to perennial grasses—throughout a field.

Incentives and policy debate: EQIP offers an incentive of $10 ($25) per acre to implement contour (strip) farming for a maximum of three years, when there is evidence that a farmer has not already been using these practices. Since these practices have long been considered necessary for growing crops on sloped fields, cost sharing for these practices is less frequently offered. However, evidence from Ohio and Maryland has shown that there is a significant positive effect of cost share incentives on the acres devoted to these practices (Mezzatesta et al., 2013; Lichtenberg and Smith-Ramirez, 2011).