Water Quality Trading in the Presence of Existing Cost Share Programs

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Abstract: Most studies of water quality trading (WQT) analyze the cost effectiveness of reducing nutrient pollution in isolation from other policies. However, the policy landscape to reduce nutrient pollution from agriculture is dominated by existing cost-share (CS) programs, which are likely to persist even after introducing WQT. We investigate empirically how these two programs are likely to interact. Using farmer survey data, we estimate the behavioral responses to a CS program aimed at increasing cover crop adoption using a two-stage simultaneous equation approach to correct for voluntary participation in the CS program. We integrate these econometric results with the Chesapeake Bay Program water quality model to evaluate the profit-maximizing decision for farmers sorting between the existing CS program and proposed WQT program. Our results indicate that farmers with comparative advantage in nitrogen abatement per acre will choose to switch into the WQT program, worsening adverse selection and increasing average payments for nitrogen abatement in the existing CS program. Actual increases in nitrogen abatement from the WQT program depend on incentivizing additional cover crop acreage without inducing slippage for those farmers not currently enrolled in the CS program.

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Water quality trading (WQT) is widely viewed as a means for reducing the cost of achieving water quality goals, with agricultural conservation practices in particular seen as an untapped low-cost supplier of nutrient emission reductions (Fisher-Vanden and Olmstead 2013). When regulated point sources (PS) have high marginal abatement costs, gains from trading can be achieved when those PS emitters purchase nutrient offset credits from low-cost nonpoint sources (NPS) such as farmers who adopt conservation practices (Horan and Shortle 2005). It is estimated that the potential saving in compliance costs from expanding WQT to meet total maximum daily load (TMDL) regulations could be $1 billion or more annually (US EPA, 2001). WQT is also promoted as a mechanism that can help reduce costs associated with asymmetric information. Rabotyagov et al. (2013) demonstrate that, when comparing WQT and two other policy approaches, the trading program can be effective in revealing the opportunity costs of adoption and provides the most cost-efficient outcomes for agricultural nutrient abatement.

An implicit assumption in prior evaluations is that the effectiveness of WQT as a market-based mechanism can be analyzed in isolation. However, federal and state cost-share (CS) programs are the dominant source of incentives for nutrient abatement from agricultural sources and will likely remain so for the foreseeable future. Federal CS programs for subsidizing conservation practices on working farmland received sharply increased funding from 2002 onward, with $2.8 billion allocated to farmers in FY2017 via the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP) (US Department of Agriculture 2017). Any proposed WQT program enters into an existing policy landscape where CS programs predominate. It is therefore essential to understand how agricultural NPS emitters will respond to the competing incentives provided under WQT and CS programs.

This paper examines interactions between WQT and CS programs. Our approach recognizes that participation in both WQT and CS programs is voluntary and thus may lead to adverse selection and unintended behavioral responses. Funded conservation practices are non-additional if they would have been implemented even in the absence of funding, a situation which occurs when private benefits exceed the costs of adoption (Horowitz and Just 2013). The empirical literature indicates that non-additionality due to adverse selection can be large enough to have an economically meaningful influence on the level of adoption (e.g., Chabé-Ferret and Subervie 2013; Mezzatesta et al. 2013; Claassen et al. 2018). Slippage may occur when payments for conservation practices make it profitable to expand crop production onto previously uncultivated land (Lichtenberg and Smith-Ramirez 2011). Since emissions are generally lower on uncultivated land (e.g., pasture or hay) than on land devoted to crop production, this effect can offset emission reduction and increase the net cost of water quality improvements (Fleming et al. 2018). Finally, receipt of a subsidy for one conservation practice can have indirect effects on the use of related practices (Fleming 2017). When accounting for these behavioral responses, actual nutrient reductions achieved can differ substantially from those reductions credited in either CS or WQT programs.

We use farmer survey data to analyze the behavioral responses to a major CS program aimed at increasing cover crop adoption in order to reduce nitrogen loads in the Chesapeake Bay. We estimate the direct effect of the cover crop CS program on the acreage share in cover crops, as well as the potential slippage effect for loss in vegetative cover and the indirect effect on conservation tillage. The treatment effects for these three farmer behavioral responses from the cover crop CS program are linked to the Chesapeake Bay Program (CBP) watershed model to estimate individual farm-level abatement of nitrogen loads delivered to the Bay. This integrated assessment model is first used to provide analysis of the farm-level cost effectiveness for nitrogen abatement in the existing cover crop CS program. We then analyze the introduction of a hypothetical trading program containing features based on the proposed WQT program in Maryland. Our main purpose is to understand how farmers are likely to respond to the differing incentive mechanisms in the WQT and CS programs. We develop a conceptual framework to show how profit-maximizing farmers currently enrolled in the existing CS program will choose between remaining in the CS program or switching to the trading program, as well as extending this framework to understand whether farmers currently not enrolled in the CS program will participate in trading. We empirically evaluate the cost-effectiveness of nitrogen abatement when the CS program is the only option, in comparison to when both programs provide competing incentives for farmers.

We estimate responses to the cover crop CS payments using a two-stage simultaneous equation approach to correct for voluntary participation in the CS program, as in Fleming et al. (2018). The first stage estimates CS program enrollment using a multivariate probit model. The second stage estimates the acreage share of conservation practices using a multivariate tobit switching regression framework with selection bias controlled for using the generalized residuals from the first stage. We estimate the change in acreage share for three behavioral responses due to cover crop CS payments: (i) the direct effect on cover crops, (ii) slippage effects on vegetative cover, and (iii) indirect effects on conservation tillage. We combine our econometric results with parameters from the CBP watershed model because this is the most policy relevant model to assess nutrient abatement in our study region since it is used by the U.S. Environmental Protection Agency (EPA) and all local jurisdictions to assess compliance with the Chesapeake Bay TMDL requirements. Our results link estimated changes in cover crop, conservation tillage, and vegetative cover acreages to nitrogen abatement in the Bay, which varies by the estimated behavioral responses at the farm level as well as land characteristics and watershed processes in different geographic segments. The resulting integrated assessment model allows us to simulate the effects of introducing a WQT program which allows payments for cover crops as a source of offset credits for regulated PS emitters.

Our analysis yields several main results. First, we show that switching from CS to WQT will occur because of a key difference in the incentive structure between the two programs: CS pays on a per-acre basis while WQT is conducted on a per-pound of nutrient reduction basis. More generally, CS programs pay for effort while WQT programs pay for performance. Farmers enrolled in the existing CS program with comparatively higher nitrogen abatement will find it more profitable selling offset credits in the WQT program over remaining in the CS program. As a result, introducing the WQT program worsens adverse selection and increases the average payment per pound of nitrogen abatement in the existing CS program. Second, farmers who switch from the CS program to the WQT program will now be paid more for the nitrogen abatement they had supplied prior to trading, as these farmers leave the CS program in order to obtain higher payments from WQT. Hence, the introduction of trading into a policy landscape dominated by CS counter-intuitively *increases* the average cost of achieving the same level of abatement previously obtained by CS alone. Finally, the increase in water pollution abatement from introducing WQT comes largely from farmers not currently enrolled in the CS program who are incentivized to adopt cover crops to sell offset credits in the WQT program. However, the cost effectiveness of abatement from this group is substantially lower after accounting for non-additionality and slippage effects. Given these behavioral responses, the individual-level abatement costs for farmers in this group are often higher than the average expected cost of the PS polluter upgrading internally, even when a trading ratio is incorporated as proposed in the Maryland WQT program. In sum, while WQT has been promoted for decades for its potential cost savings and was even the primary example used in Dales (1968) that first proposed the idea of transferable discharge permits, the extent to which those cost savings materialize depends on interactions between WQT and existing agricultural CS programs.

1. BACKGROUND

Despite extensive restoration efforts during the past 30 years, insufficient progress on water quality improvements in the Chesapeake Bay has prompted the EPA to establish TMDL regulations in 2010. The Bay TMDL is the largest ever developed by the EPA and thus has garnered national attention. It spans the entire 64,000 square mile watershed covering parts of six states—Maryland, Pennsylvania, Virginia, Delaware, New York, West Virginia plus the District of Columbia—setting pollution reduction requirements on nitrogen, phosphorus, and sediment loads entering the Bay to be attained by 2025. Nonpoint source emissions from agriculture are a major source for water quality impairment, contributing 45% of nitrogen, 44% of phosphorus, and 65% of sediment loads entering the Bay.[1]

CS programs have been the primary approach used to induce farmers to adopt conservation practices that reduce erosion and nutrient export to local waterways and the Bay. The Maryland Agricultural Water Quality Cost Share (MACS) program has been the principal source of CS funding for agricultural conservation practices, with state expenditures far in excess of federal spending in Maryland under such programs as EQIP and CSP. MACS has increasingly emphasized farmer payments for planting winter cover crops, which are now the centerpiece of Maryland's effort to abate agricultural nitrogen emissions. Cover crops are planted after cash crops are harvested in the late fall in order to absorb excess nutrients and provide soil cover during the winter on ground that would otherwise be left bare and vulnerable to erosion and nutrient runoff. The MACS cover crop program was initiated statewide in 1997. By the fall of 2009, the year analyzed in our survey, MACS funding allocated to cover crops had increased several fold to $10.7 million, representing 58% of the entire MACS budget. To make progress toward the TMDL requirements, MACS has since further increased the cover crop program budget to $24.6 million in 2016 (80% of the entire budget) providing subsidies for cover crops on approximately one-third of all cultivated cropland in the state. MACS provides a base

[1] https://tmdl.chesapeakebay.net/ .

payment set at $45 per acre in 2009 for traditional cover crops; that payment level has remained within a similar range of $45-50 per acre during recent years.

Meeting the TMDL requirements has also acted as a regulatory driver for water quality trading. Because Maryland is highly urbanized, particularly along the Baltimore-Washington corridor, the expected costs to comply with the TMDL are substantial for regulated point and urban nonpoint (e.g., stormwater) sources. The Clean Water Act (CWA) regulates point source discharges from wastewater treatment plants (WWTPs) requiring compliance with the National Pollution Discharge Elimination System (NPDES) permits. In 1987, the EPA also established the NPDES stormwater program, mandating that large municipal separate storm sewer systems (MS4s) located in jurisdictions with populations of 100,000 or more must obtain and comply with NPDES permits. Estimated costs to comply with the 2025 Bay TMDL in Maryland alone are $2.4 billion for the wastewater sector and $7.3 billion for urban stormwater management (Maryland Department of the Environment 2012). Average abatement costs for wastewater plant upgrades and stormwater management restoration strategies are considered to be several times those for agricultural best management practices (BMPs) such as cover crops (Jones et al. 2010).

Maryland has substantial potential demand from regulated point sources in water quality trading, unlike many rural regions that are dominated by cropland and not near a large metropolitan area. Yet the initial WQT program in Maryland, established prior to the TDML in 2008, had no trades (Fisher-Vanden and Olmstead 2013). The primary reason is that WWTPs were not allowed to purchase offset credits but instead were required to install specific nutrient removal technologies (Van Houtven et al. 2012); likewise, MS4 jurisdictions were not allowed to trade for stormwater management NPDES permits. After considerable planning and negotiation, the State of Maryland recently adopted revised WQT regulations in 2018 that will allow WWTPs and MS4 jurisdictions to purchase nutrient offset credits from agricultural sources.[2] These revised rules, however, stipulate that nutrient offset credits can only be used for a portion of the NPDES permit requirements and also are primarily focused on mitigating the increased loads to account for population growth. Even with these limitations, state agencies have promoted the revised WQT program as an approach to lower the compliance cost for regulated PS and to encourage additional abatement from agricultural NPS.

[2] See the Maryland Trading and Offset Policy and Guidance Manual: http://mde.maryland.gov/programs/water/Documents/WQTAC/TradingManualUpdate4.17.17.pdf

While there are no existing trades in Maryland to serve as a basis for empirical analysis, the cost-share payments provided in the MACS cover crop program provide insight into expected farmer responses to offers of payment for the voluntary adoption of cover crops and related practices. The cover crop program operates essentially in a similar manner as point/nonpoint source trading. Participation in both the WQT and cover crop program is voluntary. Farmers who choose to participate in the MACS cover crop program receive a fixed payment per acre for adopting cover crops, while those farmers who adopt cover crops for WQT would receive a payment for the nutrient offset credits supplied. While there is renewed enthusiasm for the potential benefits of trading, the MACS cover crop program has been very active and is expected to continue independently after the introduction of WQT, and even after Chesapeake Bay TMDL implementation in 2025.[3]

Understanding interactions between competing incentives in WQT and CS programs is important beyond the specifics of Maryland and the Chesapeake Bay. Although each WQT program has specific rules that vary according to the regional authorities (see Fisher-Vanden and Olmstead 2013; Shortle 2013; and Stephenson and Shabman 2017 for reviews of existing WTQ programs), all WQT programs enter into an existing landscape of federal and state cost-share programs. Moreover, newly introduced cap-and-trade programs for air pollution also interact with existing policies intended to reduce carbon emissions (Fischer and Preonas 2010). Understanding how transferable discharge permit programs are likely to compete and interact with other incentives is therefore critical for policy design and implementation planning.

2. DATA

Our empirical analysis uses data from a survey of farmers drawn from the Maryland Agricultural Statistics Service (MASS) master list of farmers in the state. The survey asked farmers whether they had implemented each of the three conservation practices studied, acreage in each practice, whether cost sharing was received from any state or federal program, and other characteristics of the farmer and farm operation in 2009. The survey questionnaire was mailed to 1,000 farm operations with telephone follow-up administered by MASS in the spring of 2010. Stratified

[3] Some jurisdictions have integrated aspects of the administration of CS and WQT programs given that these programs provide incentives to similar types of farmers in the same region, for example, in the Tar-Pamlico trading program (Breetz and Fisher-Vanden 2007).

random sampling was used to ensure sufficient response from large operations, and expansion factors were provided by MASS for deriving statewide population estimates.

We use the unweighted data in our econometric analysis and rely on robust standard errors to correct for any heteroscedasticity due to stratification of the sample, as we are interested in estimating causal effects (for a discussion of these issues see Solon et al. 2015). We use the expansion factors provided by MASS to derive population level estimates. Of the 523 responses received, 461 provided complete surveys. Survey responses were also excluded if they did not report any crops on their land (including hay and pasture), resulting in a dataset of 445 farms usable for this analysis.

Agriculture in Maryland is highly diversified, with a wide range of farm types and sizes. Appendix Table 1 shows descriptive statistics of the farm and farmer characteristics used in the econometric analysis. Cropland in the state mainly consists of corn and soybeans, with some small grains such wheat or barley. A large part of farmland in Maryland consists of vegetative cover, including hay and pasture, which is used as forage for dairy and beef cattle, horses, and other grazing animals. In our analysis, we consider vegetative cover to include hay, pasture, and other land not cultivated for crops. CS payments are not typically used for vegetative cover.

Of the 445 usable observations, 93 participated in the cover crop program (approximately 21%), while 49 adopted cover crops without receiving payment. Cover crops in the study region improve soil quality and some can be harvested or grazed in the spring. Twenty-six farmers enrolled to receive payments for conservation tillage (approximately 6% of the sample), and 191 adopted conservation tillage without payment, reflecting the fact that this practice is often profitable even when self-funded for many farmers due to the reduced labor and fuel costs and private benefits of increased soil health. CS funding for conservation tillage is available, albeit to a lesser extent than cover crops, primarily through federal programs such as EQIP and CSP. In our econometric model, we focus on cover crop cost sharing because this has been the centerpiece of Maryland’s efforts to combat agricultural nitrogen runoff into the Chesapeake Bay.

For the purpose of the econometric analysis, acreage shares in each practice are calculated as the acres devoted to a particular practice divided by the total operating acres on the farm. On average, farmers who adopt cover crops after enrolling in the cover crop program devote about a third of their operating acres to cover crops, whereas those who adopt without enrolling in the program use cover crops on only about a quarter of their acreage. Farmers who adopt conservation tillage with and without CS payments for conservation tillage use the practice on average on 56% and 55% of their acreage, respectively.

Cover crops and conservation tillage are not mutually exclusive practices, and in fact there is agronomic evidence to suggest that they are complementary in their beneficial effects. For example, cover crops help to control weed emergence in conservation tillage systems (Blum et al. 1997), and the practices work together to add increased organic matter to the soil (Balkcom et al. 2012). Empirical evidence suggests that there is positive correlation in the adoption of these practices so that CS payments for one practice may increase adoption of the other (Fleming 2017). While it is possible that payments for conservation tillage affect the use of cover crops, we expect the cover crop payments to have a larger indirect effect on conservation tillage due to the relative scale of the MACS program in the study region. Nonetheless, we account for both types of indirect effects in the econometric model.

Other variables contained in the survey include distance to the nearest water body, information on the type of nearest water body, the proportion of household income derived from farming, educational attainment, farm topography, size, number of animals of various types, and an indicator for whether the farm has 50 or more acres in corn or soybeans. Because 17 farmers in the usable sample did not provide information on the share of household income derived from farming (about 4% of the sample), a dummy variable for missing income was included in the econometric analysis to account for any systematic differences in these farmers. Finally, two variables were included to reflect the tons of erosion reduced per dollar spent on cover crops and conservation tillage, an indicator of the private benefits of these conservation practices. These variables were calculated based on parameters in the CBP watershed model—in order to obtain the tons of erosion reduced per acre of practice implementation—and the per acre cost of each practice. We use CBP erosion reduction at the edge-of-field rather than edge-of-stream to focus on the benefits considered by a profit-maximizing farmer. Costs for cover crops are based on the base payment of $45 per acre in the MACS program. Similarly, costs for conservation tillage are based on reimbursement rates from EQIP for that practice, which are in line with implementation costs from 2009 Maryland grain marketing budgets. These variables are included in the econometric model to account for the private erosion-reduction benefits of adoption of these two practices.

3. ECONOMETRIC APPROACH AND RESULTS

3.1 Econometric Model for Cost-Share Enrollment and Practice Adoption

Our empirical analysis uses the two-stage regression model with endogenous switching as formulated in Fleming et al. (2018). The first stage estimates voluntary enrollment in cost sharing for cover crops and conservation tillage using a bivariate probit model with explanatory variables Z including farm and farmer characteristics. Let cs_{ip} be a binary indicator of enrollment in program p={*cover crops*, *conservation tillage*} for farmer i, and let γ_p be a vector of parameter estimates for each program. The bivariate probit model can then be expressed as

(1) $$cs_{ip} = 1 \text{ if } Z_{ip}\gamma_p + u_{ip} \geq 0;$$

$$cs_{ip} = 0 \text{ otherwise.}$$

Error terms u_{ip} are assumed to be distributed jointly normal, with unrestricted covariance between equations representing unobserved factors that influence cost-share enrollment for both programs. Coefficients in this bivariate probit model are estimated using simulated maximum likelihood, with Cholesky factorization to solve for the off-diagonal elements of the variance-covariance matrix and a value of one on the leading diagonal.

The second stage estimates the acreage share in cover crops, conservation tillage, and vegetative cover in a trivariate tobit model. Self-selection is a well-known problem which must be considered in program evaluation with voluntary enrollment. Following Wooldridge (2014), we use a control function approach to account for the endogeneity of program enrollment by including generalized residuals from the first-stage probit model in the second-stage model. The estimated coefficient associated with the generalized residual represents the covariance between unobservables that influence the acreage share in a given practice and enrollment in cost-share program p, thereby allowing for consistent estimation of the effect of program enrollment.

The acreage share in each of the three practices is estimated with endogenous switching based on a farmer's decision to enroll in the cover crop program, the dominant cost-sharing program in the study region. That is, parameter estimates on explanatory variables X may differ based on whether or not a farmer enrolled in cover crop cost sharing. Acreage shares are censored from below at zero, while censoring from above at one is very rare in the data and thus not considered here. Let the superscript $m = \{1,0\}$ indicate with and without enrollment in the cover crop program, respectively. Further, let s_{ik} indicate the observed acreage share for farmer i

in each of the three practices *k = {cover crops, conservation tillage, vegetative cover}*. Then the trivariate tobit model is based on a latent variable, ${s^*}_{ik}^{m}$, with the following empirical specification

$$(2) \qquad {s^*}_{ik}^{m} = X_{ik}\beta_k^m + \sum_{p=1}^{2} \hat{\lambda}_{ip}\,\delta_k^m + CT_i\varphi_k^m + \varepsilon_{ik};$$

$$\text{where } s_{ik}^m = {s^*}_{ik}^{m} \text{ if } {s^*}_{ik}^{m} \geq 0,$$

$$s_{ik}^m = 0 \text{ otherwise.}$$

CT_i is a binary indicator for enrollment in conservation tillage cost sharing, which may influence the acreage share in conservation tillage, as well as the acreage shares in cover crops and vegetative cover. The estimated covariates $\hat{\lambda}_{ip}$ denote the generalized residuals from the first-stage cost-share enrollment equations for program type *p = {cover crops, conservation tillage}*, which control for nonrandom program enrollment. As in Wooldridge (2014), generalized residual $\hat{\lambda}_{ip}$ for farmer *i* in program *p* is calculated as

$$(3) \qquad \hat{\lambda}_{ip} = \phi(Z_{ip}\gamma_p)/\Phi(Z_{ip}\gamma_p) \text{ if } cs_{ip} = 1,$$

$$\hat{\lambda}_{ip} = -\phi(Z_{ip}\gamma_p)/\Phi(-Z_{ip}\gamma_p) \text{ if } cs_{ip} = 0,$$

with ϕ and Φ representing the standard normal probability density and cumulative density functions, respectively. Residuals for both program types are included in each of the three acreage-share equations to account for potential cross-practice selection bias. That is, farmers enrolled in cost-sharing for one practice may be more or less likely to place acreage in any of the three practices studied, and we therefore allow for every combination of cross-practice correlation between the enrollment and acreage-share decisions. Errors of the system of equations (2) are assumed to be distributed jointly normal, but are not observed simultaneously across regimes *m={1,0}*. The parameters of this model are estimated using simulated maximum likelihood (ML) techniques, with quasi-random Halton sequences to generate the multivariate normal random draws.

The set of farm-level variables X_{ik} that influence acreage-share decisions in equation (2) are also assumed to influence the CS enrollment decisions in equation (1), except that for purposes of identification there must be some exclusion restriction variables in Z_{ip} not included in X_{ik}. Exclusion restrictions imposed for identification are the farm's distance to the nearest water body and a binary indicator variable for whether or not the Chesapeake Bay is the nearest water body. Both variables are proxies for the water quality impacts that matter to the government agency providing cost-share funding, but not to the profit-maximizing farmers deciding on whether to adopt the conservation practice.

Limited sample size makes it desirable to utilize a more parsimonious specification featuring endogenous switching for parameters only with particular policy interest or with an a priori theoretical reason to differ. Because of the focus on the cover crop program, we allow only the coefficient estimates of the generalized residuals from the two enrollment equations, erosion reduction costs, and constant terms to differ between those who enroll in the cover crop program and those who do not. Regression analysis indicated no statistically significant differences between parameters that we did not allow to differ across regimes.

The parameter estimates from the trivariate tobit model in equation (2) are used to calculate the treatment effects for both enrolled and unenrolled farmers. Let $\hat{s}_{ik}^{1}$ and $\hat{s}_{ik}^{0}$indicate the estimated acreage shares with and without enrollment, respectively, for farmer *i* in practice *k*. For enrolled farmers, $\hat{s}_{ik}^{0}$ is the estimated counterfactual acreage share in practice *k* if a farmer had not enrolled in the cover crop program. This counterfactual estimate is obtained by combining the parameter estimates from the unenrolled group $\hat{\beta}_{k}^{0}$ with the enrolled farmer's observed covariates X_{ik}. Then the individual-level treatment effects on the treated (TET) are calculated for each enrolled farmer and conservation practice

(4) $\widehat{TET}_{ik} = \hat{s}_{ik}^{1} - \hat{s}_{ik}^{0}$, where $i \in \mathrm{I}^{1}$ for the set of enrolled farmers.

Similarly, the treatment effects on the untreated (TEU) can be calculated for each unenrolled farmer and conservation practice

(5) $\widehat{TEU}_{ik} = \hat{s}_{ik}^{1} - \hat{s}_{ik}^{0}$, where $i \in \mathrm{I}^{0}$ for the set of unenrolled farmers.

In this case, $\hat{s}_{ik}^{1}$ is the counterfactual acreage share, representing the expected acreage share in practice *k* if the farmer had been enrolled in the cover crop program.

Three treatment effects are estimated. The direct effect estimates the change in cover crop acreage share due to the cover crop program, adjusted for self-selection into the cover crop program. The slippage effect is expected to be negative, reflecting a loss in vegetative cover acreage share due to the cover crop program. Finally, the indirect effect indicates crowding-in (crowding-out) of a complementary (substitute) practice. In our analysis, we expect the indirect effect on conservation tillage acreage share due to the cover crop program to be positive, because of the agronomic complementarities between these two practices (Balkcom et al. 2012).

3.2 Econometric Results

Appendix tables A2 and A3, respectively, show the marginal effects from the bivariate probit model for enrollment and multivariate tobit model for acreage shares in the practice types. In both models, explanatory variables are significantly correlated with the dependent variables, as indicated by likelihood ratio test statistics for the hypothesis that all coefficients are equal to zero of $\chi^2_{(34)}$=190.31 (p = 0.000) for the bivariate probit model of CS program enrollment and $\chi^2_{(66)}$= 528.36 (p = 0.000) for the trivariate tobit model of acreage shares. The marginal effects of the two variables used as instruments for enrollment in CS programs are jointly different from zero at a significance level well below 1% (Wald test F-statistic of 54.91, with a corresponding p-value of 0.0000). The marginal effect of distance to the nearest water body is negative in both equations, consistent with water quality concerns being a determinant of cost-share enrollment as discussed above. The marginal effect of the indicator variable for whether or not the Chesapeake Bay is the nearest water body is positive for cover crop program enrollment and negative for conservation tillage CS enrollment, consistent with cover crop cost sharing targeted specifically toward Chesapeake Bay water quality goals. We tested for possible correlation between unobservables affecting acreage shares and the two instrumental variables using an Anderson-Rubin test. Since this test is known to be valid for linear models, we applied it using a generalized linear tobit model that transforms the dependent variable such that it is linear in parameters. This test showed that the null hypothesis of no correlation between unobservables affecting acreage decisions and the two instruments could not be rejected at any reasonable significance level (F=0.86, p=0.5219), consistent with validity of the instrumental variables (see Fleming et al. 2018).

Figure 1 shows distributions of individual-level treatment effects of the cover crop program for the three practices, as estimated using equations (4) and (5) for enrolled and unenrolled farmers, respectively. Farmers in the sample exhibit substantial heterogeneity in Figure 1, where the distributions for the individual-level treatment effects are estimated using Epanechnikov kernel functions. For the enrolled farmers, the direct effect of the cover crop program averages 0.28 with a standard deviation of 0.08, indicating that on average farmers allocate 28% more of their operating acreage to cover crops due to cover crop program enrollment. The range of this farm-level treatment effect is 0.13 to 0.53 for enrolled farmers. The indirect effect of cover crop payment on conservation tillage acreage share is 0.22 on average for enrolled farmers, with a standard deviation of 0.07 and a range of 0.06 to 0.38. The positive average treatment effect indicates the presence of crowding-in due to the agronomic complementarities between cover crops and conservation tillage. Finally, the slippage effect is -0.18 on average, with a standard deviation of 0.08 and a range of -0.06 to -0.32. The bimodal distribution of slippage is due to a highly influential indicator variable in the econometric model: the presence of grazing animals on a farm (horses, cattle, sheep or goats). Farms with grazing animals have a higher share of operating acreage in vegetative cover and are correspondingly subject to more pronounced slippage.

Now consider the TEU that estimates how farmers currently not enrolled would likely behave if they enter the cover crop program. Figure 1 shows that the direct effect for unenrolled farmers is approximately 0.25 on average, which is similar to the average direct effect for enrolled farmers. However, the distribution of direct effects on cover crops is more variable for unenrolled farmers, with a standard deviation of 0.10 and a range of 0.03 to 0.60. The indirect effects on conservation tillage are, in general, smaller among farmers not currently enrolled, averaging only 0.07, with a standard deviation of 0.04 and ranging from -0.16 to 0.18. This indicates that the indirect effect on conservation tillage would likely be smaller in many cases if cost sharing were extended to this group. Finally, the distribution of slippage effects is larger in magnitude among currently unenrolled farmers, with an average change in vegetative cover of -0.21 along with a standard deviation of 0.10 and range from -0.02 to -0.46. The distribution of slippage effects is again bimodal due to the indicator variable for whether or not grazing animals are present on a farm. In sum, Figure 1 shows that among the unenrolled farmers there is the combination of larger variability in the direct effects on cover crops, smaller indirect effects, and larger slippage effects, suggesting that behavioral responses are an important consideration when analyzing the effects of expanding incentive payments for practice adoption to farmers not currently enrolled in CS programs.

4. INTEGRATED ASSESSMENT MODEL FOR WATER QUALITY

After estimating the farm-level treatment effects of the cover crop program, we utilize parameters from the CBP watershed model to calculate nitrogen abatement on each farm due to the CS and WQT programs.[4] We begin with a description of the relevant CBP watershed model parameters, and then outline how these parameters are integrated with the econometric results to evaluate nitrogen abatement and total abatement costs from the existing CS program. We then describe how the CBP model parameters and econometric results are integrated to assess the potential participation in the proposed WQT program and provide a simple theoretical decision framework in which profit-maximizing farmers sort between the competing CS and WQT programs.

4.1 Simulating Nitrogen Abatement of the Existing CS Program

The three sets of parameters from the CBP watershed model that we utilize are nitrogen loads, practice efficiency factors, and delivery factors. First, let L_z^{crop} and L_z^{veg} represent the nitrogen loads in pounds per acre for cropland and vegetative cover, respectively.[5] These loads vary by river segment z in the CBP watershed model. Second, let e_k be an efficiency factor that represents the proportional reduction of nitrogen loads due to adoption of conservation practice k = *{cover crops, conservation tillage}*, where $0 < e_k < 1$. This efficiency factor varies for cover crops between the coastal and non-coastal plain regions, but is constant for conservation tillage throughout the study region. For vegetative cover, changes in nitrogen emissions are calculated as a change in land use from cropland to vegetative cover, not an efficiency factor, as described below. Third, let d_z be the delivery factor reflecting the share of load actually reaching the Bay from each river segment. By applying d_z to the nitrogen loads from cropland or vegetative cover, we are able to estimate changes in nitrogen loads delivered to the Bay. Finally, we match farms and river segments using each farm's zip code, which is the finest level of geographic detail available in the survey. Thus, to combine the CBP watershed model parameters with the surveyed treatment effects, we calculate weighted-average loads and delivery factors at the zip code level, allowing us to match the CBP watershed model parameters with each farm. Nitrogen

[4] While the Chesapeake Bay TMDL also targets reductions in phosphorus and sediment, our policy analysis focuses on nitrogen abatement because the primary aim of the MACS cover crop program is to reduce nitrogen loads. The root systems of cover crops are highly effective in absorbing excess nitrogen in soils after the growing season and prevent leaching of soluble nitrogen into the groundwater, while cover crops are much less effective at reducing phosphorus and sediment runoff. Moreover, nitrogen is considered the binding pollutant for meeting the TMDL requirements for the agricultural sector in Maryland and several other Bay states (Kaufman et al. 2014).

[5] The CBP model provides loads per acre from both pasture and hay, which vary by river segment. We calculate the load from a combined "vegetative cover" as the weighted-average of the observed acreage shares in pasture and hay on each farm.

abatement is therefore estimated heterogeneously for each farmer *i* in the survey, reflecting both geographic and behavioral differences.

We utilize the estimated treatment effects to calculate nitrogen abatement for the existing CS program for enrolled farmers under two scenarios. First, the baseline scenario assumes perfect additionality and ignores the slippage or indirect effects. This scenario corresponds to policy simulations that do not account for behavioral responses to incentive payments, since regulatory agencies do not observe which cover crop acres are additional nor slippage or indirect effects. In this case, the baseline scenario assumes that the acreage share in cover crops without enrollment $\hat{s}^0_{ik}$ is zero. Letting A_i represent the operating acreage of each farm, nitrogen abatement in pounds under the baseline scenario is calculated for enrolled farmer *i* as

(6) $$\Delta N_i^{Baseline} = A_i \cdot \hat{s}^1_{ik} \cdot L_i^{crop} \cdot e_k \cdot d_i, \text{ where } k = \textit{cover crop.}$$

Second, the behavioral scenario accounts for the direct effect, slippage effect due to loss of vegetative cover, and indirect effect on conservation tillage. Accordingly the nitrogen abatement in this scenario is comprised of three behavioral effects

(7) $$\Delta N_i^{Direct} = A_i \cdot \widehat{TET}_{ik}\, L_i^{crop} \cdot e_k \cdot d_i, \text{ where } k = \textit{cover crop;}$$

$$\Delta N_i^{Indirect} = A_i \cdot \widehat{TET}_{ik}\, L_i^{crop} \cdot e_k \cdot d_i, \text{ where } k = \textit{conservation tillage;}$$

$$\Delta N_i^{Slippage} = A_i \cdot \widehat{TET}_{ik}\left(L_i^{crop} - L_i^{veg}\right) \cdot d_i \text{ , where } k = \textit{vegetative cover}.$$

Total abatement for the behavioral scenario, $\Delta N^{Behavioral}$, is then the sum of these three effects

(8) $$\Delta N_i^{Behavioral} = \Delta N_i^{Direct} + \Delta N_i^{Indirect} + \Delta N_i^{Slippage}.$$

We scale up the farm-level estimates of nitrogen abatement to the statewide level in both the baseline and behavioral scenarios using survey expansion factors ω_i provided by MASS. Total abatement obtained by the CS program in the baseline scenario is then calculated as $Q^{Baseline} = \sum_i \Delta N_i^{Baseline} \cdot \omega_i$, where $i \in I^1$ for the set of enrolled farmers. Total abatement in the behavioral scenario is similarly calculated as $Q^{Behavioral} = \sum_i \Delta N_i^{Behavioral} \cdot \omega_i$, where $i \in I^1$.

In the case of slippage, when loss of vegetative cover occurs with the receipt of cover crop payments, nitrogen abatement is negative because the nitrogen loads are higher for cropland (even with cover crops) compared to loads for land devoted to vegetative cover, such as hay or pasture. The behavioral scenario tends to have lower nitrogen abatement than the baseline scenario due to slippage as well as the non-additionality from the direct effect. We compare the behavioral and baseline scenarios to understand the magnitude of the water quality impacts of behavioral responses in the cover crop program.

We calculate total cover crop program costs by using the base payment in the MACS cover crop program, r = \$45 per acre. Since cover crop program administrators do not observe non-additional acreage, nor do they account for slippage or indirect effects, the expected program costs are the same in both the baseline and behavioral scenarios, based on cover crop acreage with program enrollment, $\hat{s}_{ik}^{1}$. Specifically, the expected cover crop program cost c_i is calculated for each enrolled farmer as

(9) $$c_i = A_i \cdot \hat{s}_{ik}^{1} \cdot r, \text{ where } k=\textit{cover crops}.$$

To estimate statewide program costs, we scale the farm-level costs shown in equation (9) by the MASS survey expansion factors ω_i. We then sum these weighted costs across each enrolled farm in the sample, $TC = \sum_i c_i \cdot \omega_i$, where $i \in \mathrm{I}^1$. TC is the total expected cover crop program payment to achieve the nitrogen abatement shown in the baseline and behavioral scenarios. Average nitrogen abatement costs per pound are calculated as $TC / Q^{Baseline}$ and $TC / Q^{Behavioral}$ in the baseline and behavioral scenarios, respectively. Due to slippage and non-additional cover crop adoption, average nitrogen abatement costs are expected to be higher in the behavioral scenario.

4.2 Simulating Effects of CS and WQT Program Interaction

We use the following simplified decision model to examine how profit-maximizing farmers would sort into WQT versus the existing cover crop CS program. As before, let r denote the per-acre payment offered in the cover crop CS program. Let η_i denote the per-acre cost of cover crop use on each farm, μ_i is the per-acre private benefit (e.g., improvement in soil quality), and t_i^{cs} is the farmer's transaction costs of enrolling in the cover crop CS program. The net returns of participating in the existing CS program must be positive for each enrolled farmer such that

(10) $$r - t_i^{cs} + (\mu_i - \eta_i) > 0 \;\; \forall \; i \in \mathrm{I}^1 .$$

Meanwhile, the net returns are negative or zero for each farmer not currently enrolled in the existing CS program

(11) $$r - t_i^{cs} + (\mu_i - \eta_i) \leq 0 \;\; \forall \; i \in \mathrm{I}^0 .$$

Now consider the introduction of a hypothetical WQT program that contains features similar to the newly proposed WQT program in Maryland. The key difference in the incentive structure between the CS and WQT programs is that the CS program pays on a per-acre basis whereas trading is conducted on a per-pound basis of nutrient reduction. Let θ represent the equilibrium price (i.e., willingness to pay) per pound of nitrogen reduction demanded by regulated PS emitters, and let ζ denote the NPS/PS trading ratio in the WQT program. Let $h_i(s_{ik}*,z)$ denote the per-acre reduction in nitrogen emissions given the farmer's optimal choice of cover crop acreage (*k=cover crops*) for farmer *i* located in river segment *z*. Note that h_i = $\Delta N_i^{Baseline}/A_i$ for purposes of determining credits in a WQT program. Due to asymmetric information, WQT program managers observe only the enrolled acreage in cover crops while only farmers know their behavioral responses. We assume that all farms meet baseline requirements and are eligible to trade any nutrient credits generated with cover crop adoption. Further, any farmer enrolled in the cover crop CS program is not eligible for the same practice in the WQT program (i.e., no double dipping), as required in the proposed Maryland trading regulations. For simplicity, we also assume that transaction costs for enrollment in the two program types are approximately equal for each farmer *i*, such that $t_i^{cs} \approx t_i^{wqt} \approx t_i$. Accordingly, net returns for cover crop adoption in order to sell credits in the proposed WQT program may be expressed as

(12) $$\frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i).$$

Upon introduction of WQT in the context of an existing CS program, there are four relevant groups in which farmers sort based upon the relative profitability of the two programs. Consider first a farmer currently enrolled in the cover crop CS program. The farmer will remain in the cover crop CS program (Stayers) if the net returns are greater than or equal to those from selling offset credits

(13) Group 1: $r - t_i + (\mu_i - \eta_i) \geq \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i)$,

or $h_i(s_{ik}^*, z) \leq \zeta r/\theta, \forall\, i \in \mathrm{I}^1$.

However, a farmer currently enrolled in the CS program will switch into the WQT program (Switchers) if net returns from selling offset credits are greater than the net returns for remaining in the cover crop CS program

(14) Group 2: $\frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i) > r - t_i + (\mu_i - \eta_i)$,

or $h_i(s_{ik}^*, z) > \zeta r/\theta, \forall\, i \in \mathrm{I}^1$.

Note that the ratio $\zeta r/\theta$ represents the threshold of abatement in pounds per acre that determines the relative profitability of the CS and WQT programs. Farms with modeled baseline abatement per acre h_i that is above this threshold will receive greater returns in WQT than the CS program.

Farmers who are currently not enrolled in the cover crop CS program can be divided into two groups on the same basis as current CS enrollees. One group may choose to sell offset credits in the WQT program (Joiners) if the net returns exceed those from the CS program

(15) Group 3: $\frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i) > r - t_i + (\mu_i - \eta_i)$

or $h_i(s_{ik}^*, z) > \zeta r/\theta$, $\forall\, i \in \mathrm{I}^0$.

Another group will not sell offset credits in the WQT program (Non-participants) if the net returns are less than or equal to those in the CS program and thus the farmer participates in neither program

(16) Group 4: $r - t_i + (\mu_i - \eta_i) \geq \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i)$,

or $h_i(s_{ik}^*, z) \leq \zeta r/\theta$, $\forall\, i \in \mathrm{I}^0$.

The condition (15) defining Group 3 is clearly an upper bound on WQT participation among currently unenrolled farmers, as some farmers with abatement greater than the threshold $\zeta r/\theta$ will earn negative net returns from planting cover crops in order to sell credits in the WQT program. Basically, the left-hand side of condition (15) must be positive to ensure WQT participation; however, the right-hand side of condition (15) representing the net returns in the CS program are known to be less than or equal to zero for unenrolled farmers, according to condition (11). For this reason, the ratio $\zeta r/\theta$ is simply the lower bound threshold of abatement per acre that determines potential gains from joining the WQT program for farmers currently not enrolled in the CS program. We therefore characterize the farmers satisfying the condition (15) for Group 3 as potential WQT participants. As a result, our estimates for this group constitute an upper bound on the potential participation in the WQT program and nutrient reductions arising therefrom.

We parameterize the model as follows. We assume that the equilibrium price equals the cost of upgrading a wastewater treatment plant (WWTP), which in our study region has been estimated to be θ = \$15.80 per pound of nitrogen (Jones et al. 2010).[6] We assume that the

[6] Note that \$15.80 represents an upper bound on the willingness to pay by a WWTP in the region. WWTPs would likely negotiate a price lower than the maximum willingness to pay, and are also likely to incur transaction costs that reduce the amount they are able to profitably pay.

NPS/PS trading ratio $\zeta = 2$, as specified in the proposed Maryland trading regulations for trades between the WWTP and agricultural sectors. We do not adjust abatement from WWTPs for delivery factors to the Chesapeake Bay.[7] The cover crop payment r is defined at \$45 per acre in the MACS program. Together, these parameters establish a threshold of abatement, $\zeta r/\theta$ equal to 5.7 pounds per acre, which is compared with baseline farm-level abatement h_i when determining the sorting of a farm between the WQT and cover crop programs. The WQT program managers apply the baseline scenario estimates, $h_i = \Delta N_i^{Baseline}/A_i$, for nitrogen abatement when evaluating the number of credits that a given farmer generates with cover crop adoption. Farmers currently enrolled in the cover crop CS program with modeled baseline abatement less than 5.7 pounds per acre will remain in the CS program (Stayers), while those with abatement greater than 5.7 pounds per acre will switch to the WQT program to sell nutrient offset credits (Switchers). Farmers currently not enrolled in the cover crop CS program with baseline abatement less than 5.7 pounds per acre will participate in neither program (Non-participants), while current non-enrollees may choose to sell nutrient offset credits if their baseline abatement is greater than 5.7 (Joiners).

We estimate the cost of achieving nitrogen emissions reductions from nutrient trading on each farm by multiplying estimated reductions in emissions $\Delta N_i^{Baseline}$ by the effective credit price of \$7.90 per pound given the trading ratio, p/ζ. Specifically, the expected WQT program cost c_i^{wqt} for farmer i in Groups 2 and 3 is calculated as

$$c_i^{wqt} = \Delta N_i^{Baseline} \cdot p/\zeta \ . \tag{17}$$

For currently unenrolled farms such as those in Group 3, baseline emissions reductions $\Delta N_i^{Baseline}$ are derived from the estimates of cover crop acreage in the counterfactual scenario of program enrollment as shown in equation (6).[8]

We calculate total statewide costs of the WQT program by scaling these farm-level costs with the MASS expansion factors ω_i, similar to the approach above for calculating the statewide cost for the cover crop CS program. Specifically, $TC^{cs} = \sum_i c_i^{cs} \cdot \omega_i$, where i is separately summed for the subset of farmers in Group 1, while $TC^{wqt} = \sum_i c_i^{wqt} \cdot \omega_i$, where i is separately

[7] Many large WWTPs in Maryland are located adjacent to the Bay and thus have a delivery load factor $d = 1$.
[8] Note that the econometric model derives the counterfactual cover crop acreages for currently unenrolled farmers—$\hat{s}_{ik}^1 \ \forall \ i \in \mathrm{I}^0$—by combining the set of explanatory variables X_{ik} of unenrolled farmers with the parameter estimates $\hat{\beta}_k^1$ from the enrolled group in the switching regression model.

summed for the subset of farmers in Group 2 and Group 3, respectively. The average abatement costs in the CS program for Group 1 are calculated in the same way as discussed in the preceding section for the existing CS program, except that the total costs and total abatement calculations are summed over only the subset of farmers in Group 1. Average abatement costs for the WQT program in the baseline scenario, $TC^{WQT}/Q^{Baseline}$ are equal by definition to the per-pound cost of credits, since $Q^{Baseline} = \sum_i \Delta N_i^{Baseline} \cdot \omega_i$, leading to the expression

$$\text{(18)} \qquad TC^{WQT}/Q^{Baseline} = \left(\frac{\sum_i c_i^{wqt} \cdot \omega_i}{\sum_i \Delta N_i^{Baseline} \cdot \omega_i}\right) = \left(\frac{\sum_i \Delta N_i^{Baseline} \cdot \theta/\zeta \cdot \omega_i}{\sum_i \Delta N_i^{Baseline} \cdot \omega_i}\right) = \frac{\theta}{\zeta},$$

where i is summed separately for the subset of farmers in Group 2 and 3, respectively. Meanwhile, average abatement costs for the WQT program in the behavioral scenario are

$$\text{(19)} \qquad TC^{WQT}/Q^{Behavioral} = \left(\frac{\sum_i c_i^{wqt} \cdot \omega_i}{\sum_i \Delta N_i^{Behavioral} \cdot \omega_i}\right) = \left(\frac{\sum_i \Delta N_i^{Baseline} \cdot \theta/\zeta \cdot \omega_i}{\sum_i \Delta N_i^{Behavioral} \cdot \omega_i}\right) = \frac{\theta}{\zeta}\left(\frac{Q^{Baseline}}{Q^{Behavioral}}\right).$$

The relative difference between average WQT abatement costs in the baseline and behavioral scenarios in equations (18) and (19) demonstrates the extent to which baseline estimates used to determine credit supply overestimate the actual abatement achieved at a statewide level.

5. POLICY SIMULATION RESULTS

We begin with a discussion of nitrogen abatement and cost-effectiveness under the existing cover crop program alone prior to the introduction of WQT. The aim is to evaluate the current effectiveness of the cover crop program for nutrient abatement when considering behavioral responses relative to baseline estimates. We then discuss how the introduction of a hypothetical WQT program is expected to interact with the existing cover crop program in order to assess which farmers would sort into the WQT versus cover crop program. We then summarize the implications for the cost-effectiveness and actual nitrogen abatement of both programs.

5.1 CS Program Prior to Introduction of WQT

When only the cover crop CS program is available, statewide cover crop acreage enrolled is estimated to be 305,884 acres, with a corresponding program cost of \$13.7 million. Under the baseline scenario, the reduction in nitrogen emissions into the Bay is 1.98 million pounds (Table 1). After accounting for behavioral responses, however, estimated nitrogen abatement is only 1.19 million pounds, about three-fifths of the baseline estimate. The average cost of nitrogen abatement is \$6.93 per pound under the naïve baseline estimate but about two-thirds higher (\$11.52 per pound) when behavioral adjustments are taken into account.

Figure 2 compares the nitrogen abatement per acre of cover crops for the baseline and behavioral estimates. Farmers currently enrolled in the CS program exhibit considerable heterogeneity. It is noteworthy that nitrogen abatement on most farms lies below the 45 degree line, indicating that slippage effects and non-additionality decrease the nitrogen abatement achieved with cover crop planting relative to baseline estimates. In more extreme cases, the behavioral estimate indicates negative nitrogen abatement, which occurs because the slippage effect outweighs the nitrogen abatement from both the direct effect of cover crop adoption and indirect effects on conservation tillage.

Figure 3 shows supply curves for nitrogen abatement obtained by plotting abatement cost per pound in ascending order against cumulative abatement under both the baseline and behavioral scenarios. A comparison of the two estimated abatement supply curves shows that marginal abatement costs are substantially higher than the baseline estimates at all levels of cumulative abatement once behavioral adjustments are taken into account. The supply curves in Figure 3 only include farms with positive levels of abatement cost per pound and exclude the subset of farmers with negative abatement for the behavioral scenario (shown in Figure 2). As a result, a comparison of the supply curves in Figure 3 understates the difference between the baseline and behavioral scenarios.

5.2 Interactions between CS and WQT Programs

The CS and WQT programs differ fundamentally in terms of incentive payment structure, with the CS program paying per acre of cover crops while WQT pays per pound of nitrogen reduction for cover crop planting according to estimates from the CBP watershed model. That distinction implies that farmers currently enrolled in the CS program with comparatively higher nitrogen abatement will sort into the WQT program while current CS program enrollees with lower nitrogen abatement levels will remain in the CS program, as can be seen from conditions (13) and (14). Under the parameterization of our model, the threshold for this sorting occurs at a baseline estimate of 5.7 pounds per acre, shown as a vertical line in Figure 2. Current CS program enrollees with baseline abatement lying to the right of this vertical line will sort into the

WQT program (Switchers), while current CS enrollees with nitrogen abatement lying to the left of the vertical line will remain in the CS program (Stayers).

Figure 3 depicts the sorting of current CS program enrollees into Stayers and Switchers using a supply-demand framework. The horizontal line depicts demand for offset credits at the average cost of $7.90 per pound, representing the purchase of credits by WWTPs with average cost of internal upgrades at $15.80 per pound and a NPS/PS trading ratio at 2:1. Current CS program enrollees that have low marginal abatement costs below the horizontal demand curve would sort into the WQT program (Switchers), while those with higher marginal abatement costs would remain in the CS program (Stayers). While the specific sorting threshold will vary in different regions, generally the adverse selection problem in CS programs will be exacerbated upon introduction of trading. Intuitively, this worsening of adverse selection occurs because the WQT program attracts current CS program enrollees with the greatest comparative advantage in abatement and thus the lowest marginal abatement costs (and correspondingly greater ability to profit from WQT).

This worsening of adverse selection is illustrated numerically in Table 1, which summarizes the nitrogen abatement and cost-effectiveness for the relevant groups of farmers that sort between the CS and WQT programs. The current CS enrolled farmers sort into two groups—those that remain in the CS program (Stayers) and those that switch to the WQT program (Switchers). As expected, those remaining in the CS program receive higher average payments for nitrogen abatement in column [2], in comparison to the existing CS program prior to WQT in column [1]. Using the behaviorally-adjusted estimates, average costs in the CS program increase by 73% (from $11.52 to $19.93 per pound) after the most cost-effective CS enrollees switch to the trading program.

Current CS enrollees who are cannibalized by the WQT program also receive higher average nitrogen abatement payments at $13.35 per pound, compared to the existing CS program in column [1]. The reason is that, prior to WQT, the CS program was the only option for high-abatement farms. When the WQT and CS programs compete, these high-abatement farmers pursue larger payments by switching to WQT. Despite the expected cost effectiveness of trading as a policy instrument, introducing WQT into an existing CS policy landscape will increase total payments made for achieving the same level of nitrogen abatement previously obtained by the CS program alone. Specifically in Table 1, the CS program alone shows the statewide nitrogen abatement of 1.19 million pounds for the behavioral scenario at a total cost of $13.8 million, whereas the same farmers (Switchers and Stayers) achieve the same abatement at a combined program cost of $17.1 million, meaning that costs increased by 24% following WQT. While the magnitude of this increased cost will depend on the specific geographic region, the main result holds in general so long as the Switchers leave the CS program to obtain higher payments via trading.

Finally, the estimates of participation in WQT from farmers currently not enrolled in the CS program in column [4] of Table 1 represent an upper bound on potential acreage enrolled and nitrogen reductions from this group, as noted previously. This group may account for up to 365,244 acres, representing the majority of the estimated total cover crop acreage planted under the newly-introduced WQT program. However, the Joiners exhibit much higher slippage levels and non-additional adoption than the Stayers and Switchers (see Figure 2). As a result, estimated nitrogen abatement adjusted for farmer behavioral effects is only 45% of the baseline estimate. The average cost of nitrogen abatement correspondingly increases to $17.63 per pound, or more than double the baseline average cost of $7.90 per pound. In fact, this average payment for nitrogen abatement from the Joiners—once adjusted for slippage, indirect effects, and non-additionality—now exceeds the average cost of internally upgrading WWTPs at $15.80 per pound, indicating that much of the cover crop acreage provided by this group is not actually a cost-reducing source of nitrogen abatement.

While the magnitude of non-additional adoption and slippage effects among farmers that join WQT will likely vary for different regions, we emphasize more generally that NPS/PS trading ratios may not be adequate to guarantee the cost-effectiveness of WQT if those ratios do not account for behavioral responses of voluntary WQT program participants. The CBP watershed model parameters account for spatial heterogeneity when used to estimate nitrogen abatement by NPS emitters; and the State of Maryland has proposed a 2:1 NPS/PS trading ratio as an additional adjustment to accommodate uncertainty (e.g., weather-induced randomness) of abatement from agricultural NPS emitters. However, our estimates indicate that these combined adjustments fail to control for slippage and non-additional adoption that can cause actual nitrogen abatement achieved to be substantially less than baseline estimates used by the program administrators to track progress in meeting the TMDL.

The potential for adverse behavioral responses by voluntary trading participants implies a need for safeguards that should be included in any NPS/PS trading contract. One possible mechanism is to create contracts stipulating that only farms with recorded cropping histories are eligible for cover crop payments, to ensure that land previously in vegetative cover is not converted to cropland. Currently the CS and WQT programs require that only fields currently in cropland are allowed to be enrolled for cover crop payments. But this requirement does not prevent a farmer from converting cropland in the spring to be eligible for cover crop payment in the fall. A longer cropping history requirement, such as evidence of crop production during the past five years, would reduce the potential perverse incentive for farmers to convert hay and pasture land into cropland.

6. CONCLUSION

WQT programs are widely considered a cost-effective policy instrument to achieve water quality goals, with the agricultural sector in particular seen as a low-cost supplier of nutrient credits. An implicit assumption of many prior evaluations of WQT is that the incentives provided can be analyzed in isolation from existing agricultural CS incentive programs. Yet WQT programs enter into a policy landscape dominated by CS programs, which will likely remain even as WQT programs are introduced. This study investigates the likely interactions between these two types of programs in the context of Maryland's cover crop CS program and a proposed WQT program. We develop a conceptual framework to elucidate how these two programs might interact. We then use survey data to estimate farm-level responses to cover crop payments to understand the behavioral effects of the existing cover crop CS program and understand empirically how the CS and WQT programs are likely to interact.

Our analysis yields several main results and policy implications. First, our estimates indicate that the WQT program has the potential to attract substantial sales of nutrient reduction credits from the agricultural sector. However, we find that a significant share of those credits will come from farmers currently enrolled in the CS program; thus, analysis of the potential for trading to improve water quality, which ignores existing CS programs, will tend to overstate new reductions in nitrogen emissions. Second, the introduction of WQT worsens the adverse selection problem of CS programs, as farmers with a comparative advantage in higher abatement levels are the most likely to switch to WQT. Third, because high-abatement farms leaving the CS program do so in order to obtain higher payments in the WQT program, introducing a WQT program will increase expenditures needed to achieve the same level of abatement previously obtained in the CS program. Finally, the nitrogen abatement from introducing WQT depends largely on the response of high-abatement farmers not currently enrolled in the CS program. We find that the total nitrogen abatement from this group joining the WQT program would substantially increase the amount obtained from the existing CS program. However, the farm-level behavioral responses from this group result in levels of non-additional cover crop acreage and slippage that can be quite large, sometimes even perversely leading to increases in nutrient emissions. After accounting for these behavioral responses, the resulting abatement costs among this group are often higher than the cost of point source internal upgrades, even when a 2:1 trading ratio is incorporated.

Our findings indicate the importance of understanding the interactions between different policy instruments aimed at the same goal and available to the same groups of agents. Trading has the well-known potential for cost-savings. Yet the actual environmental benefits accomplished by introducing a new trading policy, like WQT, will depend on how it interacts with existing subsidy programs. For trading programs to achieve their potential, it is essential to have a realistic understanding of how they might fit within existing pollution abatement policy and to design their operating procedures accordingly.

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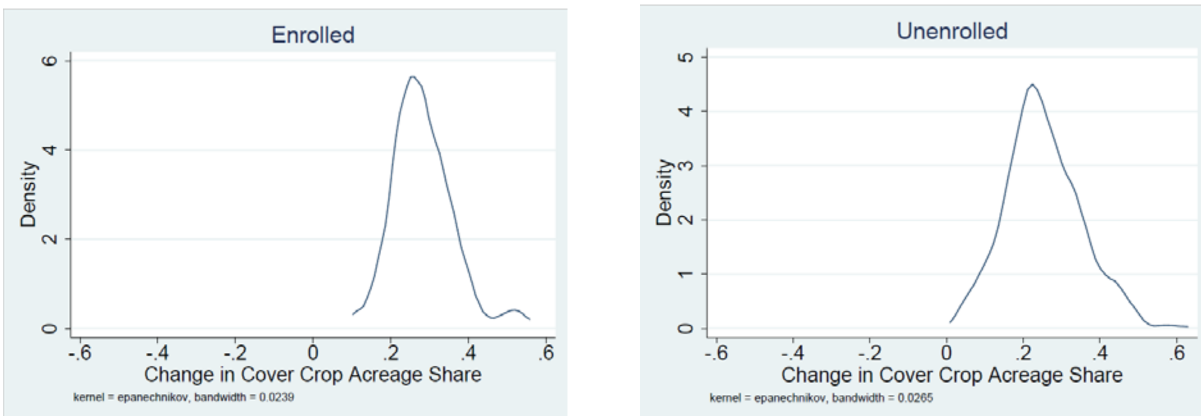
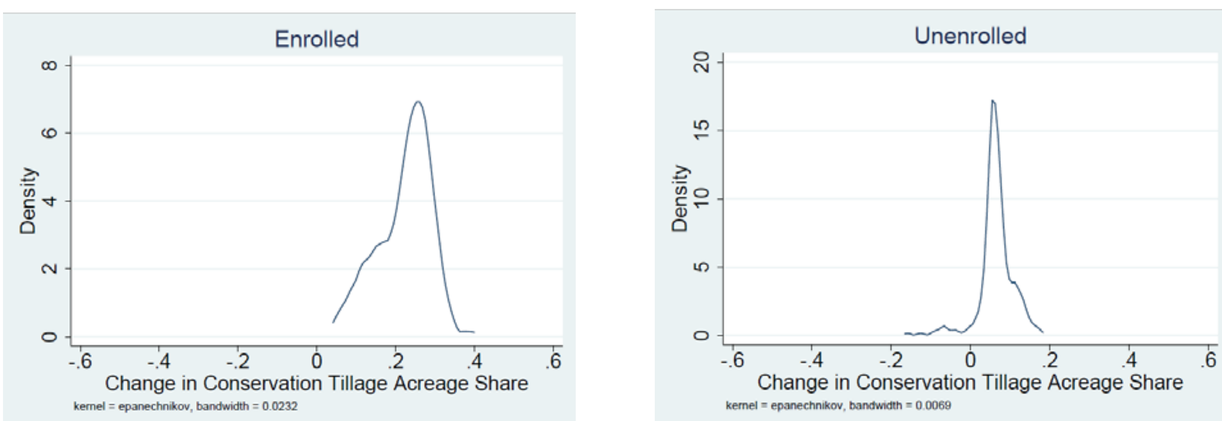
FIGURES

Direct Effect: Change in Cover Crop Acreage Share



Indirect Effect: Change in Conservation Tillage Acreage Share



Slippage Effect: Change in Vegetative Cover Acreage Share

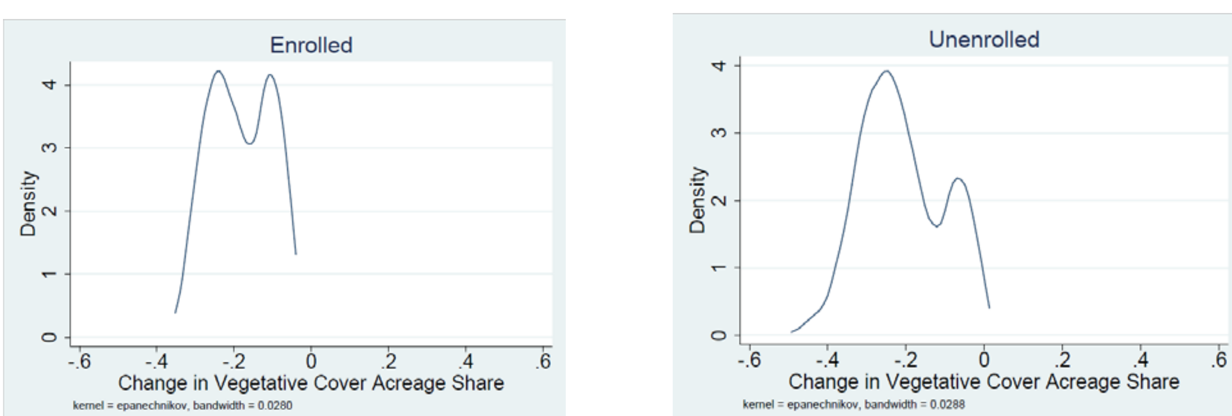


Figure 1. Distribution of Farm-Level Treatment Effects on Acreage Shares in Conservation Practice due to Cover Crop Cost-Share Program

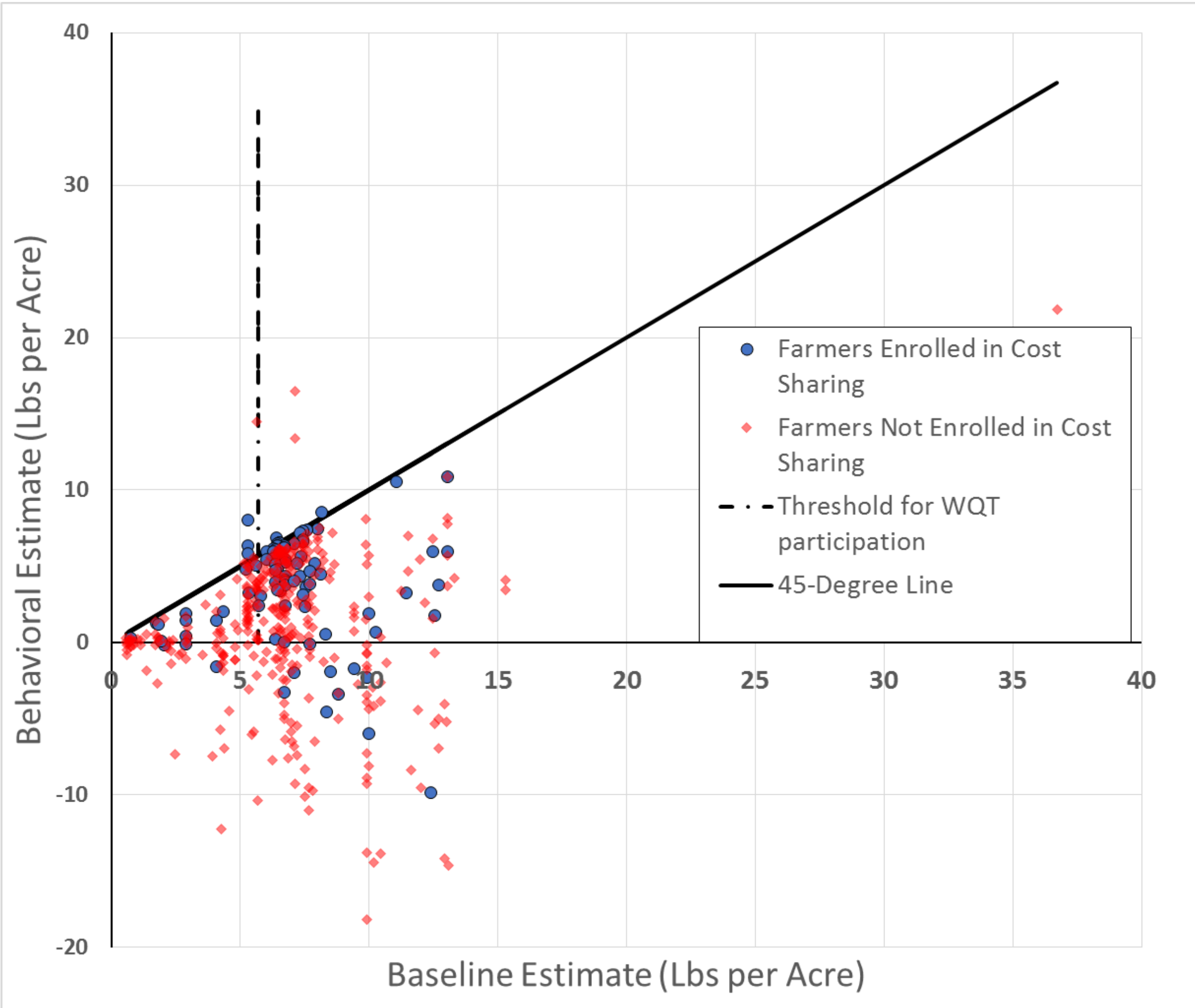


Figure 2. Behavioral and Baseline Estimates of Nitrogen Emission Reductions from Cover Crop Adoption

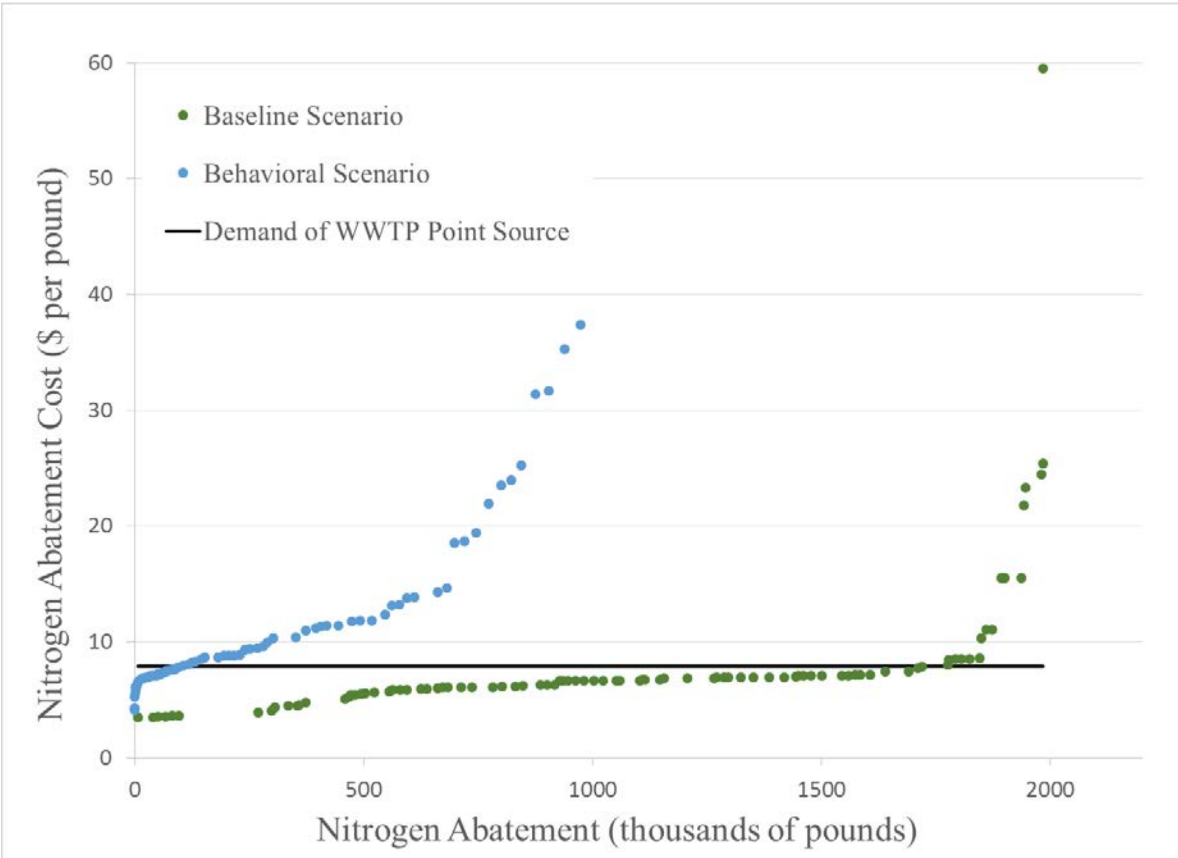


Figure 3. Supply Curve on Nitrogen Abatement for Farmers Enrolled in Cover Crop Program

TABLES

Table 1. Nitrogen Abatement and Cost-Effectiveness with and without Water Quality Trading (WQT) Program

	CS Program Only	CS and WQT Programs Both Available			
	Current CS Enrollees	Stayers: Current CS Enrollees Remaining in CS Program	Switchers: Current CS Enrollees Switching to WQT Program	Joiners: Current CS Non-Enrollees Selling Credits in WQT Program	Total for Both CS and WQT Programs
	[1]	[2]	[3]	[4]	[5]
Cover crop acreage	305,844	77,792	228,052	365,244	671,088
Total program payments	$13,762,962	$3,500,635	$13,596,256	$22,582,369	$39,679,260
Baseline scenario**:**					
N abatement (lbs.)	1,984,963	263,917	1,721,045	2,858,528	4,843,490
Average cost ($/lb.)	$6.93	$13.26	$7.90	$7.90	$8.19
Behavioral scenario:					
N abatement (lbs.)	1,194,221	175,608	1,018,613	1,281,200	2,475,420
Average cost ($/lb.)	$11.52	$19.93	$13.35	$17.63	$16.03

Appendix Tables

Table A1. Descriptive statistics of farmer survey

Variable	Mean	Std. Dev.	Min	Max
Enrollment in cover crop cost sharing (1=yes)	0.21	0.4	0	1
Enrollment in cons. tillage cost sharing (1=yes)	0.06	0.2	0	1
Acreage share in cover crops	0.08	0.2	0	1
Acreage share in conservation tillage	0.27	0.4	0	1
Acreage share in vegetative cover	0.31	0.3	0	1
Distance to the nearest water body (miles)	0.45	1.4	0	11
Chesapeake Bay nearest water body (1 = yes)	0.07	0.3	0	1
Proportion income from farming	0.55	0.4	0	1
Missing data for "Proportion income from farming" (1=missing)	0.04	0.2	0	1
Highest level of education attained				
Did not graduate high school	0.15	0.4	0	1
High school grad or some college	0.60	0.5	0	1
Completed college or graduate school	0.25	0.4	0	1
Proportion acres in slope class				
Flat (< 2% grade)	0.50	0.4	0	1
Moderate (2-8% grade)	0.42	0.4	0	1
Steep (>8% grade)	0.08	0.2	0	1
Log operating acres	5.15	1.6	0.69	9.19
Log grazers (horses, sheep, goats, beef)[a]	1.78	2.0	0	7.17
No grazers (1 = no grazers)	0.45	0.5	0	1
Log dairy[a]	0.80	1.9	0	7.47
No dairy (1 = no dairy)	0.83	0.4	0	1
Log poultry[a]	0.21	1.1	0	7.63
No poultry (1 = no poultry)	0.96	0.2	0	1
Farmer grows 50 or more acres in corn and/or soybeans (1 = yes)	0.49	0.5	0	1
Erosion reduction benefit (tons reduced / $)				
Cover crops	0.476	0.256	0.122	1.499
Conservation tillage	0.812	0.437	0.208	2.556

N=445 for all variables.

[a] When observations have no livestock, the undefined log values are coded to zero.

Table A2. Marginal Effects for Multivariate Probit Model of Enrollment in Cost-Share Programs by Practice Type

	Cover crop	Conservation tillage
Distance to the nearest water body (miles)	-0.0127*	-0.0172*
	(0.0076)	(0.0104)
Nearest water body is the Bay (1 = yes)	0.0133	-0.3448***
	(0.0392)	(0.0247)
Highest level of education completed		
High school or some college	0.091***	0.0696**
	(0.0327)	(0.0317)
Completed college or graduate school	0.1461***	0.0692**
	(0.0381)	(0.0353)
Proportion acres in slope class		
Moderate (2-8% grade)	0.067***	0.0235
	(0.0247)	(0.0202)
Steep (> 8% grade)	0.0179	-0.0741
	(0.0776)	(0.0693)
Log operating acres	0.0225*	-0.0041
	(0.0135)	(0.0074)
Log grazers (horses, goats, sheep, or beef)	0.0084	0.0024
	(0.0120)	(0.0088)
No grazers (1 = no grazers)	-0.0001	-0.0078
	(0.0521)	(0.0381)
Log dairy cattle	0.0154	0.0194
	(0.0201)	(0.0153)
No dairy (1 = no dairy)	0.0696	0.1326*
	(0.1051)	(0.0792)
Log poultry	-0.0203	0.0152
	(0.0240)	(0.0140)
No poultry (1 = no dairy)	-0.1257	0.0537
	(0.1264)	(0.0747)
Farmer grows 50 or more acres in corn and/or soybeans (1 = yes)	0.1524***	0.0354
	(0.0363)	(0.0251)
Proportion income from farming	0.0663*	0.0458*
	(0.0382)	(0.0252)
Missing data for "Proportion income from farming" (1=missing)	-0.5489***	-0.2998***
	(0.0521)	(0.0262)
Erosion benefit (tons reduced / $)		
Cover crops	-0.0838*	-
	(0.0461)	

Conservation tillage	-	-0.0233
		(0.0275)
Observations	445	445

Note.—Robust standard errors in parentheses.
* p < 0.10; ** p < 0.05; *** p < 0.01.

Table A3. Marginal Effects for Multivariate Tobit Model of Acreage Shares With and Without Enrollment in Cover Crop Cost-Share Program

	Cover crop		Conservation tillage		Vegetative cover	
	With Enrollment	Without Enrollment	With Enrollment	Without Enrollment	With Enrollment	Without Enrollment
Highest level of education completed						
High school or some college	-0.0319		0.016		0.0922*	
	(0.0235)		(0.0446)		(0.0487)	
Completed college or graduate school	-0.0234		0.0007		0.1787***	
	(0.0282)		(0.0564)		(0.0550)	
Proportion acres in slope class						
Moderate (2-8% grade)	0.0009		0.0714**		0.0337	
	(0.0138)		(0.0331)		(0.0331)	
Steep (> 8% grade)	-0.0843**		0.0289		-0.0303	
	(0.0331)		(0.0723)		(0.0687)	
Log operating acres	-0.005		-0.0113		-0.0239*	
	(0.0069)		(0.0147)		(0.0139)	
Log grazers (horses, goats, sheep, or beef)	-0.0031		0.0028		0.0356***	
	(0.0039)		(0.0142)		(0.0108)	
No grazers (1 = no grazers)	-0.014		0.007		-0.1605***	
	(0.0184)		(0.0553)		(0.0434)	
Log dairy cattle	0.0071		-0.0189		0.0302	
	(0.0092)		(0.0217)		(0.0238)	
No dairy (1 = no dairy)	0.0406		-0.0208		0.0731	
	(0.0456)		(0.1018)		(0.1002)	
Log poultry	0.0069		0.0437		-0.0324	
	(0.0139)		(0.0421)		(0.0380)	
No poultry (1 = no dairy)	-0.0015		0.1667		-0.1417	
	(0.0703)		(0.2573)		(0.1594)	
50 or more acres in corn and/or soybeans (1 = yes)	0.0124		0.2363***		-0.1782***	
	(0.021)		(0.050)		(0.047)	
Proportion income from farming	0.0299*		0.0388		-0.0181	
	(0.017)		(0.042)		(0.045)	
Missing data for "Proportion income from farming" (1=missing)	0.0385		-0.0332		-0.0899	
	(0.027)		(0.077)		(0.058)	
Cons. tillage enrollment (1 = yes)	-0.0684		-0.1387		0.0994	
	(0.080)		(0.197)		(0.249)	
Erosion benefit (tons reduced / $)						
Cover crops	-0.1403	0.0348*	-	-	-0.1707	0.0172
	(0.1355)	(0.0180)			(0.1183)	(0.0533)

Conservation tillage	-	-	-0.0477	0.0048	-	-
			(0.1323)	(0.0329)		
Lambda (covariance w/ cover crop cost share)	-0.0264	-0.0212	-0.0126	-0.0817	0.111	0.101
	(0.1030)	(0.0285)	(0.1455)	(0.0822)	(0.0769)	(0.0884)
Lambda (covariance w/ cons. tillage cost share)	0.1024	-0.003	0.1577	0.1184	-0.0529	-0.0451
	(0.1525)	(0.0275)	(0.1936)	(0.0884)	(0.1005)	(0.1275)
Observations	445		445		445	

Note.—Robust standard errors in parentheses.
* p < 0.10; ** p < 0.05; *** p < 0.01.