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 these programs in isolation from other policies intended to reduce pollution from nonpoint sources. However, the policy landscape to reduce nonpoint source pollution from agriculture is dominated by cost-sharing (CS) programs, which are likely to remain upon introduction of new WQT programs. We use a survey of farmers in Maryland to estimate behavioral responses to environmental payments for cover crop adoption. We find substantial heterogeneity in the way farmers respond to CS payments for cover crops, including varying degrees of non-additionality, slippage effects on vegetative cover, and indirect effects on conservation tillage. We integrate these econometric results with the Chesapeake Bay Program model to define a profit-maximizing sorting rule for farmers between an existing CS program and proposed WQT program. Enrolled farmers with the highest on-farm abatement optimally switch into the WQT program, worsening adverse selection and increasing average nitrogen abatement costs in the CS program by 73%. Environmental benefits of WQT depend on the program's ability to incentivize farmers previously not participating in the CS program to adopt additional cover crop acres without inducing slippage.

Keywords: water quality trading, cost sharing, nonpoint source pollution, payment for environmental services, multiple simultaneous equations, Chesapeake Bay, adverse selection
JEL codes: C34, H23, Q52, Q53, Q58

Selected paper prepared for presentation at the 2018 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, Washington, DC, August 5-7.

I. Introduction

Agricultural non-point source (NPS) emissions of nutrients and sediment remain the dominant cause of water quality impairment in the United States. Because NPS pollution from agricultural fields has been largely unregulated under the Clean Water Act (CWA), voluntary conservation programs providing incentive payments and technical assistance from federal and state programs are the primary mechanism to encourage the adoption of conservation practices. In 2002, federal cost-share funding has increased sharply for conservation practices on working lands, with $2.4 billion allocated to farmers in the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP). At the same time that EQIP funding increased in 2002, other program changes were mandated by Congress that lowered program effectiveness such as reduced emphasis on benefit-cost targeting, elimination of bidding for cost-share funding, and reduced targeting at the farm and watershed levels (Claassen, Cattaneo, and Johansson 2008; Garnache et al. 2016).

Further, participation in cost-share programs is voluntary and thus may lead to adverse selection. Funded conservation practices may be non-additional if they would have occurred even in the absence of cost-share funding when the private benefits exceed the costs of practice adoption (Horowitz and Just 2013). The empirical literature indicates that non-additionality can be large enough to have an economically meaningful influence on the level of practice adoption (e.g., Chabé-Ferret and Subervie 2013; Mezzatesta, Newburn and Woodward 2013; Claassen, Duquette, and Smith 2018) and emission reductions (Fleming et al. 2018). Slippage may also occur when cost-share payments for conservation practices make it profitable to expand crop production onto previously uncultivated land (Bushnell and Chen 2009; 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 slippage effect can offset emission reduction thereby lowering the cost effectiveness of cost-share programs for water quality improvements (Lichtenberg and Smith-Ramirez 2011; Fleming et al. 2018).

Water quality trading (WQT) has been widely viewed as an efficient approach to reduce the cost of achieving water quality goals, with agricultural practices in particular seen as an untapped low-cost supplier of nutrient emission reductions (US Environmental Protection Agency 2001; Fisher-Vanden and Olmstead 2013). Point sources, such as wastewater treatment plants, are required to install costly upgrades to reduce emissions in order to comply with the National Pollution Discharge Elimination System (NPDES) permits under the CWA. WQT programs, often spurred by establishment of total maximum daily load (TMDL) requirements, may reduce the compliance costs for point sources. Specifically, when regulated point sources have high marginal abatement costs, gains from trading can be achieved by purchasing nutrient offset credits from farmers paid to adopt conservation practices (Horan and Shortle 2005). The anticipated cost savings in meeting TMDL requirements have been the motivation for the nearly dozen WQT programs established in the United States. Few if any trades have occurred in these trading programs for a variety of reasons on both demand and supply sides, as outlined in recent reviews on WQT programs (Fisher-Vanden and Olmstead 2013; Shortle et al 2013; Stephenson and Shabman 2017). Nonetheless, it is estimated that the potential saving in compliance costs from expanding WQT to meet TMDL regulations could be $1 billion or more annually (US Environmental Protection Agency 2001).

WQT is often promoted because this market-based mechanism helps reduce costs associated with asymmetric information, whereas the effectiveness of cost-share programs is often hampered because the agency has limited information on farm-level adoption costs for conservation practices. Rabotyagov, Valcu, and Kling (2013) demonstrate that, when comparing

WQT and two other policy approaches, the trading program is effective in revealing the opportunity costs of adoption and provides the most cost-efficient outcomes for agricultural nutrient abatement. An implicit assumption in this study and others is that the effectiveness of WQT as a market-based mechanism can be analyzed in isolation. However, federal and state cost-share programs are the dominant source of incentives for agricultural nutrient abatement and will likely remain so for the foreseeable future. Any proposed WQT program therefore enters into an existing policy landscape where cost-share programs predominate. It is essential to understand the niche for a proposed WQT program and how farmers will respond to the multiple competing incentives provided under WQT and cost-share programs.

In this study, we use farmer survey data to analyze the behavioral responses to a major cost-share program to incentivize cover crop adoption aimed at reducing nitrogen loads in the Chesapeake Bay. We estimate the direct effect of the cover crop cost-share program on the acreage share in cover crops, as well as the potential slippage effect for loss in vegetative cover and indirect effect on conservation tillage. The treatment effects for these three farmer behavioral responses are linked to the Chesapeake Bay Program (CBP) watershed model to estimate the water quality impacts on nitrogen loads delivered to the Bay. This analysis provides an initial baseline assessment of the heterogeneity in farm-level cost effectiveness for nitrogen abatement in response to the existing cover crop cost-share program. We then analyze the introduction of a hypothetical trading program that contains features based on the newly proposed WQT program in Maryland established to offset future growth of point source discharges. Our main purpose is to understand how farmers respond to the competing incentive mechanisms in the WQT and cost-share programs. We also aim to evaluate the cost-effectiveness when the cost-share program is the only option, as well as when both programs provide competing options for farmers.

For the econometric model, we estimate responses to the receipt of cover crop cost-share payments using a two-stage simultaneous equation approach to correct for voluntary participation in the incentive program. The first stage estimates program enrollment in a multivariate probit model. The second stage estimates the acreage share of conservation practices adopted in response to payment in a multivariate switching regression framework using quasi-random Halton sequences. We estimate the change in acreage share for three distinct responses: (i) cover crops (direct effect of payment), (ii) vegetative cover (potential slippage effects), and (iii) conservation tillage (potential indirect effects on a related practice with agronomic complementarities). 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 EPA and all jurisdiction to assess compliance with the Bay TMDL requirements. Our results translate estimated changes in practice acreage to changes in nitrogen delivered to the Bay, which vary by estimated behavioral responses as well as land characteristics and watershed processes in different geographic segments.

Our policy simulation results are relevant both for understanding farmer behavioral responses to cost-sharing programs as they exist, and also how these programs will interact with potential WQT programs. First, we find that farmers exhibit substantial heterogeneity in their behavioral response to cost-sharing payments. Estimates of nitrogen abatement that account for behavioral responses of (i) non-additionality, (ii) slippage, and (iii) indirect effects are substantially lower than baseline policy simulation estimates that assume all subsidized acreage is additional. In some cases, the large farm-level estimates of slippage even perversely outweigh the nitrogen abatement of additional cover crop adoption following payment, resulting in increased nitrogen discharges.

Our results also have important policy implications for the interaction of potential WQT programs with existing cost share programs. First, based on a simple profit-maximizing sorting rule, we find that the majority of enrolled farmers in our study region would likely leave the cost-share program in favor of the new WQT program, at existing cost-share payment rates and nutrient credit prices based on the costs of point source upgrades. Because the farms most likely to leave the cost-share program are those with higher abatement per acre, this exodus would exacerbate the adverse selection problem already present in the cost-share program. In the case of Maryland's cover crop program, average abatement costs would increase by 73% following the introduction of a WQT program. Second, interestingly the WQT program that cannibalizes the existing cost-share program also increases the overall cost to society of achieving the abatement that had previously been achieved by the cost share program alone. This is because the high-abatement farms leaving the cost share program do so in order to obtain higher payments in the WQT program. We find that total social costs to achieve the same abatement previously achieved by cost sharing (after accounting for behavioral responses to both programs) increases by 24% following the introduction of WQT. Finally, the net environmental benefit of introducing a WQT program in a policy landscape already dominated by cost-share programs is entirely from the currently unenrolled farms who may be incentivized to participate in WQT due to the potential for higher payments. The unenrolled farms most likely to participate in a WQT program are those with higher abatement on their farms. The nitrogen abatement that may be achieved by this group of potential WQT participants is more than twice that obtained by current enrollees in the cost-share program. However, after accounting for behavioral responses to cover crop payments by this group of farmers—including non-additionality and slippage—further unintended consequences may emerge. While point sources save money by trading with farmers, standard trading ratios are not always sufficient to guarantee that the abatement actually achieved by these trades is less costly than what would have been obtained had the point source polluter simply upgraded internally at their expected cost.

II. 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]

Cost-share subsidy programs have been the primary approach used to incentivize 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 cost-share funding for agricultural conservation practices, with state expenditures far in excess of federal spending in Maryland under such programs as the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (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.

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

Cover crops are planted after cropland is cultivated in the late fall, absorbing excess nutrients and providing soil cover during the winter that would otherwise be left bare and vulnerable to erosion and nutrient runoff. MACS funding for cover crops was initiated in 1997. By 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 further increased the cover crop program 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 payment set at $45 per acre in 2009 for traditional cover crops, which has remained approximately 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 sources. The CWA of 1972 regulates point source discharges from wastewater treatment plants (WWTPs) requiring compliance under the NPDES permits. Starting 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 (MDE, 2012). Marginal abatement costs for wastewater plant upgrades and stormwater management restoration strategies are several fold higher than 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 in the proximity of a large metropolitan area. Yet the initial WQT program in Maryland, established prior to the TDML in 2008, had no trades (Fisher-Vanden and Olmsted 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), and 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 point sources and to encourage additional abatement from agricultural NPS sources.

While there are no existing trades in Maryland for empirical analysis, there is a need to understand how farmers may respond to financial incentives to supply of nutrient credits. The cost-share payments provided in the MACS cover crop program provide insight into the expected behavioral response for the adoption of cover crops and related practices. The cover crop program operates essentially in a similar manner as PS-NPS trading. Participation in both the WQT and cost share 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 per the nutrient offset credit

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

supplied. Importantly, while there is renewed enthusiasm for the potential benefits of trading, the MACS cost-share program has been very active and is expected to continue until Bay TMDL completion in 2025 and beyond. This interaction between competing incentives in WQT and cost-share programs is broadly relevant. Although any WQT program has specific rules that vary according to the regional authorities (see Fisher-Vanden and Olmsted 2013; Shortle et al. 2013 for a review of existing WTQ programs), these trading programs enter into an existing landscape of federal and state cost-share programs, such as the EQIP incentives for cover crops or other conservation practices on working lands.

III. Data

We use data from a survey of Maryland farmers drawn from the Maryland Agricultural Statistics Service (MASS) master list of farmers. The survey contains information on cost-share participation, the use of cover crops and other BMPs, characteristics of the farm operation, farm finance, and farm operator demographics for the year 2009. The survey questionnaire was mailed to 1,000 farm operations with telephone follow-up administered by MASS in the spring of 2010. Stratified 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 for example 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. Cost-sharing 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 harvested or grazed in the spring can be used as forage for livestock in the study region. 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. Cost-share funding for conservation tillage is available, albeit to a lesser extent than cover crops, and 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 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 with cost sharing devote about a third of their operating acres to cover crops, whereas those who adopt without receiving incentive payments use cover crops on only about a quarter of their acreage. Farmers who adopt conservation tillage with and without cost-sharing 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 (Balkom et al. 2012). Empirical evidence suggests that there is positive correlation in the adoption of these practices such that cost-share 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 practice cost per acre. 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.

IV. Econometric Approach and Results

Our econometric analysis is based on a two-stage regression model with endogenous switching. In the first stage, we estimate 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. In the second stage, we estimate the acreage share in cover crops, conservation tillage, and vegetative cover in a trivariate tobit model with endogenous switching based on a farmer's choice to participate in the cover crop program, the dominant cost sharing program in the study region. That is, the acreage share in each of the three practices is estimated based on explanatory variables X whose estimated parameters may differ based on whether or not a farmer enrolled in cover crop cost sharing. Enrollment in cost sharing for conservation tillage is included as a covariate in X. We use a control function approach to account for the endogeneity of voluntary program enrollment by including generalized residuals from the first-stage probit model in the second-stage tobit model (see for example Wooldridge 2010). This allows for consistent estimates of acreage shares in the presence of endogenous enrollment.

For purposes of identification, some variables included in the matrix Z must be excluded from the matrix X. We use the farm's distance to the nearest water body (in miles) and an indicator variable for whether or not the Chesapeake Bay is the nearest water body as the instrumental variables included in *Z* but excluded from *X*. Both of these variables are proxies for the environmental benefits of BMP adoption, which matter for the regulatory agency making the decision to grant cost-share funding, but ostensibly would not influence a profit-maximizing farmer's decision of whether or not to adopt the conservation practice. Let the superscript cs = *{1,0}* indicate with and without enrollment, respectively, in the cover crop cost sharing program. Further, let s_{ik} indicate the observed acreage share for farmer *i* in each of the three practices *k* = *{cover crops, vegetative cover, conservation tillage}*. Then the multivariate tobit model is based on a latent variable, s^{*cs}_{ik}, with the following empirical specification:

$$s^{*cs}_{ik} = X_i \beta^{cs}_k + \varepsilon_{ik}; \tag{1}$$

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

$$s^{cs}_{ik} = 0 \text{ otherwise.}$$

Errors of the system of equations (1) are assumed to be distributed jointly normal, but are not observed simultaneously across regimes *cs={1,0}*. The parameters of this model are estimated using simulated ML techniques, with quasi-random Halton sequences to generate the multivariate normal random draws.

Note that the vector of parameter estimates β is estimated separately for farmers with and without cover crop cost sharing. However, due to limited sample size we favor a more parsimonious specification when doing so does not reduce the information gained. Regression analysis indicated that in most cases β^1_k was not significantly different from β^0_k. For this reason, we allowed endogenous switching for parameters only with particular policy interest or with an expected theoretical reason to differ. There were no statistically significant differences between parameters that we did not allow to differ across regimes. Appendix tables A2 and A3 show the marginal effects from the multivariate probit and multivariate tobit models, respectively.

The parameter estimates from the multivariate tobit model are used to calculate the effects of cover crop payments for the group of enrolled 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.[3] Then the treatment effects are calculated, in terms of the change in acreage shares, *TET*, for each enrolled farmer and each conservation practice:

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

Similarly, the treatment effects can be calculated for each unenrolled farm and conservation practice:

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

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

Three treatment effects are estimated. The change in the cover crop acreage share measures the direct effect of cover crop payment receipt, adjusted for self-selection into the cover crop program. The change in the vegetative cover acreage share measures the slippage or leakage effect due to expansion of crop cultivation onto previously uncultivated land caused by cover crop payment receipt. Finally, the change in the conservation tillage acreage share is a measure of the indirect effect of cover crop payment receipt due to crowding-in (crowding-out) of a complementary (substitute) conservation practice (Fleming 2017).

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[3] This counterfactual is obtained by combining the parameter estimates from the unenrolled group $\hat{B}_{k}^{0}$, with the enrolled farmers' observed covariates *X*.

The farmers in the sample exhibit substantial heterogeneity in the estimated treatment effects on each of the three practices (Figure 1). Here we focus on the treatment effects on enrolled farmers for the sake of brevity, and because the WQT program will directly compete for the participation of this group. The direct effect of the cover crop program averages 0.28 with a standard deviation of 0.09, indicating that on average farmers allocate 28% more of their operating acreage to cover crops due to cost-share enrollment. The range of this treatment effect for each enrolled farmer is 0.06 to 0.63. The indirect effect of cover crop payment on conservation tillage averages around 0.11, again with a standard deviation of about 0.09 and a range of -0.16 to 0.41. 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 averages around -0.20 with a standard deviation of 0.10 and a range of -0.02 to -0.46. 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). On these farms there is a higher share of operating acreage in vegetative cover, which causes the estimated slippage effect to be more pronounced.

V. Methodology for Policy Simulation and Water Quality Trading Participation

After estimating the treatment effects of cover crop payments on each farm, we utilize data from the U.S. EPA's Chesapeake Bay Program (CBP) watershed model to calculate reductions in nitrogen (N) on each farm due to cost-share (CS) program enrollment and WQT participation.[4]

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[4] While the Chesapeake Bay TMDL also targets reductions in phosphorus (P) and sediment, this analysis focuses on N because cover crops are primarily intended for nitrogen abatement. The root systems of cover crops prevent leaching of soluble N into the groundwater, but in comparison to other practices are less effective at reducing P and sediment runoff. Moreover,

We begin with a description of the CBP model parameters, and how these parameters are applied to the existing CS program. We then describe how these model parameters are used to estimate participation in a hypothetical WQT program that competes with the existing CS program.

We use three sets of parameters from the CBP model. First, let L_s^{crop} and L_s^{veg} be measures of nitrogen loads (in pounds) produced by an acre of cropland and vegetative cover, respectively.[5] These loads vary by river segments, s, in the CBP model. Second, let e_k be the efficiency factor expressed as the proportional reduction of nitrogen load 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, nitrogen abatement is calculated as a change in land use from cropland to vegetative cover, not an efficiency factor, as shown below. Third, let d_s be the delivery factor reflecting the share of load actually reaching the Bay from each modeled river segment. By applying d_s to the edge-of-stream abatement, we are able to estimate changes in nitrogen in the Bay itself due to practice adoption. 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 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 parameters with each farmer in the survey.

Simulating Effects of the Existing CS Program

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nitrogen is considered the binding nutrient for eutrophication from agriculture in Maryland (Shortle 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.

We utilize the estimated treatment effects to calculate nitrogen abatement and expected costs of the existing CS program in two scenarios. First, the baseline scenario assumes perfect additionality and no slippage or indirect effects. This corresponds to standard 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 counterfactual acreage share in cover crops is zero. Thus, nitrogen abatement (in pounds) is calculated as follows, where A_i represents the operating acreage of each farm:

$$\Delta N_i^{Baseline} = A_i \cdot X_i^1 \hat{B}_k^1 \cdot L_i^{crop} \cdot e_k \cdot d_i, \text{ where } k = \textit{cover crop.} \tag{4}$$

Second, the behavioral scenario allows for non-additionality, slippage effects due to loss of vegetative cover, and indirect effects on conservation tillage. Accordingly the nitrogen abatement in this scenario is composed of three effects:

$$\Delta N_i^{Direct} = A_i \cdot \widehat{TET}_{ik}\, L_i^{crop} \cdot e_k \cdot d, \text{ where } k = \textit{cover crop;} \tag{5}$$

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

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

The total abatement, $\Delta N^{Behavioral}$, is then the sum of these three effects.

$$\Delta N_i^{Behavioral} = \Delta N_i^{Direct} + \Delta N_i^{Indirect} + \Delta N_i^{Slippage} \tag{6}$$

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 in vegetative cover, such as hay or pasture. For this reason, along with non-additionality shown in the direct effect, abatement in the behavioral scenario tends to be lower than the baseline scenario. We compare this aggregated behavioral abatement with the baseline scenario in order to understand the magnitude of the environmental implications of behavioral responses to cover crop payments.

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

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

The sum of c_i across all enrolled farms is the total expected CS program payment to achieve the nitrogen abatement shown in the baseline and behavioral scenarios. Average costs per pound N reduced are calculated as $(\sum_i c_i)/\sum_i \Delta N_i^{Baseline}$ and $(\sum_i c_i)/\sum_i \Delta N_i^{Behavioral}$ in the baseline and behavioral scenarios, respectively. Due to slippage and non-additional cover crop adoption, the average costs per pound N reduction are expected to be higher in the behavioral scenario.

Simulating Effects of CS and WQT Program Interaction

To analyze the introduction of a hypothetical WQT program and how it competes with the existing CS program, we make the following model assumptions. On the demand side, we assume that wastewater treatment plants (WWTPs) have the option to upgrade the plant internally at an average cost of p, which in our study region is p = \$15.80 per pound N (Jones et al. 2010). The trading ratio is 2:1 for WWTP point sources that purchase nutrient credits from agricultural nonpoint sources, as stated in the Maryland trading regulations.[6] Hence, the point

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[6] http://mde.maryland.gov/programs/water/Documents/WQTAC/TradingManualUpdate4.17.17.pdf

source has an upper bound willingness to pay, $WTP = p / 2$ = \$7.90 per pound, for a nitrogen offset credit from the agricultural sector. For simplicity, we also assume that there are no transaction costs between the treatment plant (buyer) and farmer (seller). Therefore, the demand for nitrogen credits in the WQT program is $WTP = p / TR$, where TR is the program's trading ratio between point and nonpoint sources.[7]

On the supply side, due to asymmetric information, the WQT program manager merely observes the enrolled acreage in cover crops, whereas only farmers know their behavioral response. Therefore the WQT program manager applies the baseline scenario estimates, $\Delta N_i^{Baseline}$, for nitrogen abatement when evaluating the number of credits that a given farmer generates with cover crop adoption. We assume that all farms meet baseline requirements and are eligible to trade any nutrient credits generated with cover crop adoption, and that a farmer enrolled in the CS program for cover crops is not eligible for the same practice in the WQT program (i.e., no double dipping), as required in the Maryland trading regulations.

Therefore farmers currently enrolled in the CS program must choose whether to sort into the WQT program or remain in the CS program. Given that the CS program has a fixed payment rate r = \$45 per acre, the farms with higher baseline abatement per acre optimally sort into the WQT program, whereas farms with lower baseline abatement optimally remain in the CS program. A farmer's optimal sorting decision occurs at a threshold defined as $t = r / WTP$. In our case, this threshold is 5.7 pounds per acre, calculated as \$45 per acre divided by \$7.90 per pound. With a baseline farm abatement of greater than t pounds per acre, farmers will choose the WQT program because their modeled abatement multiplied by the price of selling credits, $WTP =$

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[7] Many large WWTPs in Maryland are located adjacent to the Bay, such that the delivery load factor is $d = 1$.

\$7.90 per pound, is greater than the MACS payment of r = \$45 per acre. Those farmers with modeled baseline abatement less than 5.7 pounds per acre will remain in the CS program. Letting h_i represent each farm's modeled baseline abatement per acre (which can be calculated as $\Delta N_i^{Baseline}/A_i$), the optimal sorting decision for enrolled farmers is made as follows:

(8) Enter the WQT program if $h_i > \frac{r}{WTP}$, remain in the CS program otherwise, for each already enrolled farmer i.

For unenrolled farmers, the sorting rule is similar in nature. Those currently unenrolled farmers with high nitrogen abatement per acre, over h_i = 5.70 pounds per acre, may sell credits in the WQT program given that it is more profitable than the existing payment from the CS program. Meanwhile, other unenrolled farmers with low abatement per acre will neither participate in the WQT nor CS program. This leads to three groups of interest for the interaction of the CS and WQT programs. Group 1 is composed of CS-enrolled farmers who remain with the CS program ($h_i \leq r/WTP$, where $i \in I^1$). Group 2 is composed of CS-enrolled farmers who are likely to be cannibalized by the WQT program (enrolled farmers for which $h_i > r/WTP$, where $i \in I^1$). Group 3 are those farmers not enrolled in the CS program but who are potential WQT participants ($h_i > r/WTP$, where $i \in I^0$).

Intuitively, another approach to understand the farmer decision is to examine a supply curve of nitrogen abatement. The WQT program awards nutrient credits according to the baseline estimates. Farmers currently enrolled that have low nitrogen abatement cost under *WTP* = \$7.90 per pound for the baseline supply curve would be more profitable switching to the WQT program. The currently enrolled farmers remaining in the CS program would be those with higher nitrogen abatement cost. Thus, the adverse selection problem of CS programs is exacerbated.

VI. Policy Simulation and Water Quality Trading Results

We first provide a discussion of the policy simulation and nutrient abatement results for the CS program, prior to the introduction of the WQT program. The aim is to explain the current effectiveness of the CS program for nutrient abatement when comparing the baseline scenario (perfect additionality) and behavioral scenario. Then we discuss how the introduction of a hypothetical WQT program is expected to interact with the current CS program. The purpose is to assess which farmers would sort into the WQT versus CS program, and summarize the implications for the cost-effectiveness and environmental benefits of both programs.

Policy Simulation Results – Cost Sharing Program Only

To begin, Table 1 shows the nitrogen abatement obtained by farmers enrolled in the CS program for both the baseline and behavioral scenarios. Under the CS program statewide total cover crop acreage enrolled is estimated to be 305,884 acres, using the survey expansion factors. The total program cost is $13.7 million based on the $45 per acre base payment in the MACS program. Under the baseline scenario, the nitrogen abatement for the Bay is 1.98 million pounds. After accounting for behavioral responses, however, the estimated nitrogen abatement is only 1.19 million pounds. Hence the average cost effectiveness is $6.93 per pound for the naïve baseline estimate, but the implied cost effectiveness for actual nitrogen abatement is 66% more costly in the behavioral scenario.

Figure 2 shows the farm-level heterogeneity in nitrogen abatement in pounds per acre in cover crops under the baseline and behavioral estimates. Considerable heterogeneity exists for the current enrolled farmers, where most farms fall below the 45 degree line indicating that the slippage effect in particular is decreasing the nitrogen abatement achieved with cover crop adoption. In more extreme cases, the behavioral estimate is negative for nitrogen abatement, which occurs primarily because the slippage effect counteracts the nitrogen abatement from both cover crop adoption and indirect effects on conservation tillage. Figure 3 provides the supply curves for the cost per pound of nitrogen abatement under the baseline and behavioral scenarios. These curves demonstrate the substantial heterogeneity in marginal abatement costs achieved by the CS program in the study region, ranging from under $5 to $40 per pound for the majority of farmers. Figure 3 also clearly shows the magnitude of the increased abatement cost after accounting for behavioral response. It should be noted that these supply curves only include positive levels of cost per pound and thus the actual distinction between behavioral and baseline supply curves is even larger than that shown in Figure 3, because the subset of farmers with negative abatement in Figure 2 due to high slippage effects in the behavioral estimate cannot be represented in the supply curve in Figure 3.

Policy Simulation Results – Interaction between CS and WQT Programs

In addition to depicting the heterogeneity in farmer behavioral response to existing CS programs, Figures 2 and 3 also provide a clear depiction conceptually of how farmers would sort into the CS and WQT programs. For example, on the demand side, Figure 3 shows a horizontal demand curve for nitrogen credits in a WQT program at $7.90 per pound, representing the purchase of credits by wastewater treatment plants.[8] On the supply side, the vertical line in Figure 2 shows the sorting of farmers between the CS and WQT programs at a threshold of 5.7 pounds per acre,

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[8] The horizontal line implies perfectly elastic demand at a cost no higher than average WWTP upgrades at $15.80 per pound (Jones et al. 2010) under a 2:1 ratio for trades between point sources and agricultural nonpoint sources.

as described in Equation (8), where farmers with modeled abatement above h_i would optimally sort into the WQT program since the payment received at *WTP* =\$7.90 per pound would exceed the flat CS base payment of *r*=\$45 per acre. Farmers with modeled abatement below this threshold would optimally remain in the CS program. Thus, the adverse selection of CS programs is exacerbated.

Table 2 shows the nitrogen abatement and cost-effectiveness for the three relevant groups of farmers under competition between the CS and WQT programs, as defined in Equation (8). The currently enrolled farmers in the CS program sort into two groups—those farmers that remain in the CS program (Group 1) and those farmers that switch to the WQT program (Group 2). As expected, the farmers remaining in the CS program have a higher average abatement cost at \$19.93 per pound for the behavioral estimate (Group 1), in comparison to the pre-existing CS program in Table 1 with an average cost of only \$11.52 per pound. The problem of adverse selection in CS programs, exacerbated by the introduction of the WQT program, increased the average costs of abatement achieved by the CS program by 73%.

Interestingly, the currently enrolled farmers that are cannibalized by the WQT program also have a higher abatement cost at \$13.35 per pound (Group 2) when compared to the pre-existing CS program in Table 1. The reason is that, prior to the WQT program, the CS program was the only option for farmers with high pollution abatement potential, such that it drove down the average abatement cost in the CS program as seen in Table 1. When the WQT and CS programs compete for the currently enrolled farmers, the farmers will extract more payments such that the average abatement costs will increase for both Groups 1 and 2. Thus, a further effect of introducing the WQT program into an existing CS policy landscape is that the total costs of achieving the abatement previously achieved by the CS program (1.194 million pounds across the state in the behavioral scenario) are increased by 24%. However, only $3.5 million are now paid by the CS program, with the remaining $13.6 million paid by buyers of nitrogen credits in the WQT program.

Finally, Table 2 also shows the currently unenrolled farmers who may participate in the WQT program (Group 3). If all the farmers with loads per acre greater than the threshold *t* enter the program, Group 3 contributes an estimated total cover crop acreage of 365,244 acres, more than doubling the acreage enrolled under the existing CS program in Table 1. The total nitrogen abatement potentially achieved by unenrolled farmers entering the WQT program is 2.8 million pounds under the baseline estimate, which by itself is 44% higher than that achieved by enrolled farmers. However after accounting for behavioral effects the nitrogen abatement potentially achieved is less than half of this amount, and only 7% higher than what is estimated to be achieved by enrolled farmers in the behavioral scenario.

The WQT program has a trading ratio of 2:1 which accounts for the higher uncertainty in nutrient abatement from nonpoint agricultural sources. Our estimates show that the behavioral responses are larger than the trading ratio, particularly due to the slippage effects for unenrolled farmers in Group 3 (see Figure 2). For this reason the average abatement cost at $17.63 per pound for Group 3 is higher than the WWTP upgrade cost of $15.80 per pound. While WWTP plants save money by trading with the currently unenrolled farms in Group 2, from a societal perspective the abatement achieved from these trades is costlier than what would have been achieved if the WWTP had simply internally upgraded at the expected cost of $15.80 per pound (Jones et al. 2010).

The WQT program would be able to improve cost-effectiveness if there are any mechanisms that can be instituted to reduce the slippage effect. A potential policy recommendation is to require that only farms with recorded cropping histories are eligible for cover crop payments, to ensure that land previously in vegetative cover is not lost to cropland. Currently the CS and WQT program require that only farms that are currently in cropland are allowed to enroll in cover crop payments. But this does not prevent a farmer from converting cropland in this year without cover crops to be eligible for payment the following year. A cropping history requirement, such as evidence for crop production during the past five years, would reduce the potential perverse incentive for farmers to convert hay and pasture land into cropland.

VII. 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 assessments of WQT is that the incentives provided can be analyzed in isolation from existing agricultural cost-share incentive programs. Yet this policy arena is currently dominated by cost-share programs, which will likely remain in place even as WQT programs are introduced. In this study, we use survey data to analyze the farm-level responses to CS payments for cover crops to understand both the behavioral effects of CS programs as they exist, and also how these programs will interact with the introduction of a proposed WQT program.

We find substantial heterogeneity in farmers' behavioral responses to CS payments. Estimates of nitrogen abatement that account for the behavioral responses of non-additionality, slippage effects on vegetative cover, and indirect effects on conservation tillage are lower than baseline policy simulations that assume perfect additionality. On some farms, the slippage estimates are large enough to outweigh additional cover crop adoption, resulting in increased nitrogen emissions following payment. Aside from these extreme cases, the implied cost of nitrogen abatement within the cover crop program range from under $5per pound to over $40 per pound for enrolled farmers.

This farm-level heterogeneity has important policy implications for the introduction of a potential WQT program. First, based on a profit-maximizing decision framework by which farmers sort between the two programs, the introduction of WQT worsens the adverse selection problem of CS programs. Farmers with higher abatement per acre are likely to switch to WQT in pursuit of larger payments. In our study region, this results in a 73% increase in average costs per pound N abatement in the CS program. Second, because high-abatement farms leaving CS do so in order to obtain higher payments in the WQT program, the total cost to society of achieving the same level of abatement previously obtained in the CS program increases by 24% following the introduction of WQT. Finally, the added environmental benefits of introducing WQT in the presence of CS programs is entirely dependent on the response of high-abatement farmers previously not participating in the CS program, who may be attracted by the potential for higher payments with WQT. We find that potential abatement from this group could more than double the N abatement obtained from the existing CS program. However, our estimates of non-additional cover crop acreage and slippage among this group of farmers is larger than the 2:1 trading ratio—resulting in implied abatement costs among this group that are higher than the cost of point source upgrades, after accounting for these behavioral responses.

A general implication of this study is that potential WQT programs should not be analyzed in isolation from the existing policy landscape within which they will operate. A WQT program that intends to utilize the agricultural sector to supply credits should be designed with an awareness of its likely interaction with CS programs. Effluent trading has a well-known potential for cost-savings. Yet the environmental benefits from a WQT program that incentivizes practices already covered by CS will depend entirely on the behavioral response of unenrolled farms, particularly the enrollment of additional conservation acreage without inducing slippage. It is necessary to approach potential WQT programs with a realistic understanding of how they fit within existing agricultural NPS pollution policy.

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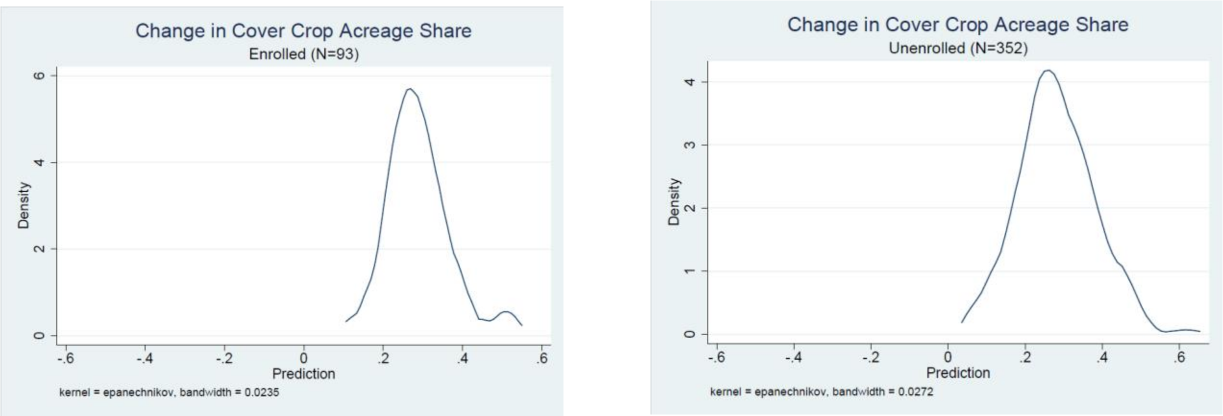
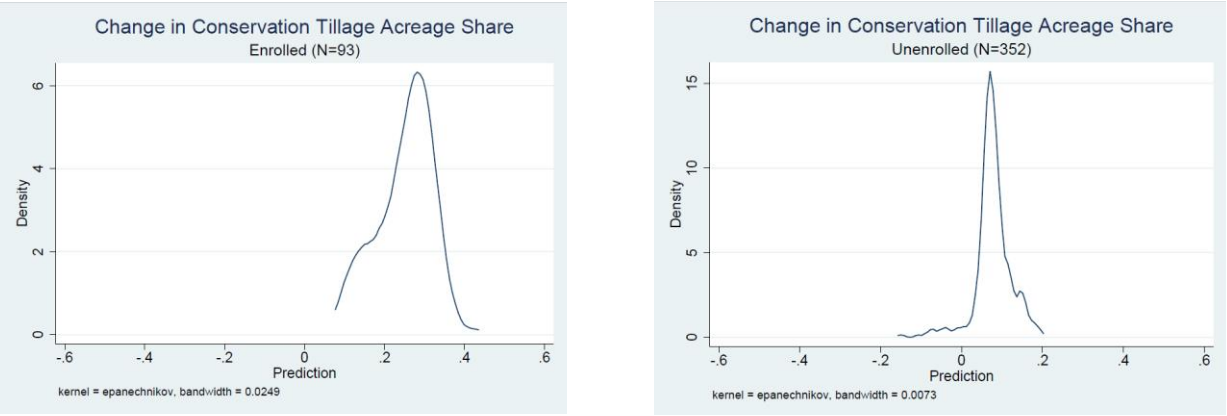
Figures

Direct Effect:



Indirect Effect:



Slippage Effect:

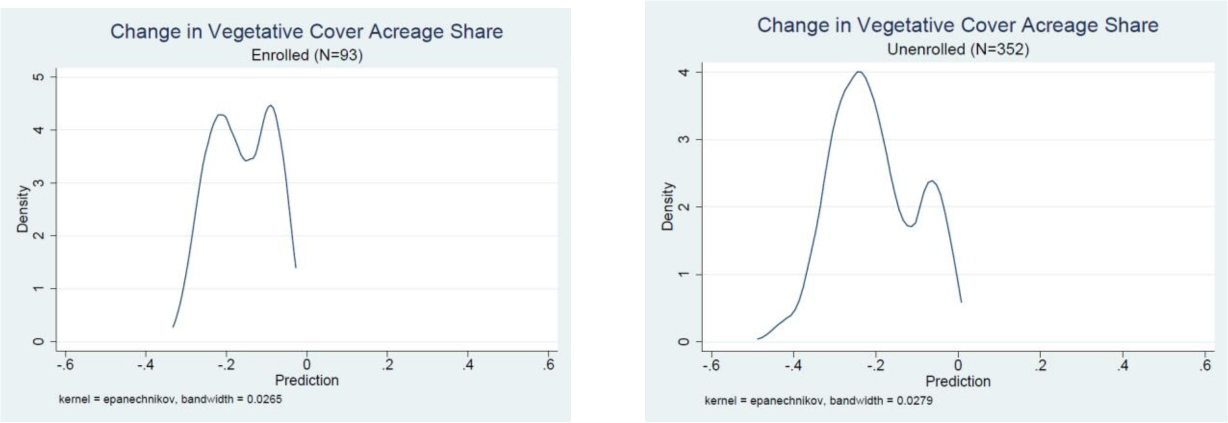


Figure 1. Distribution of Behavioral Effects of Cover Crop Payments on Acreage Shares at the Individual Farm-Level

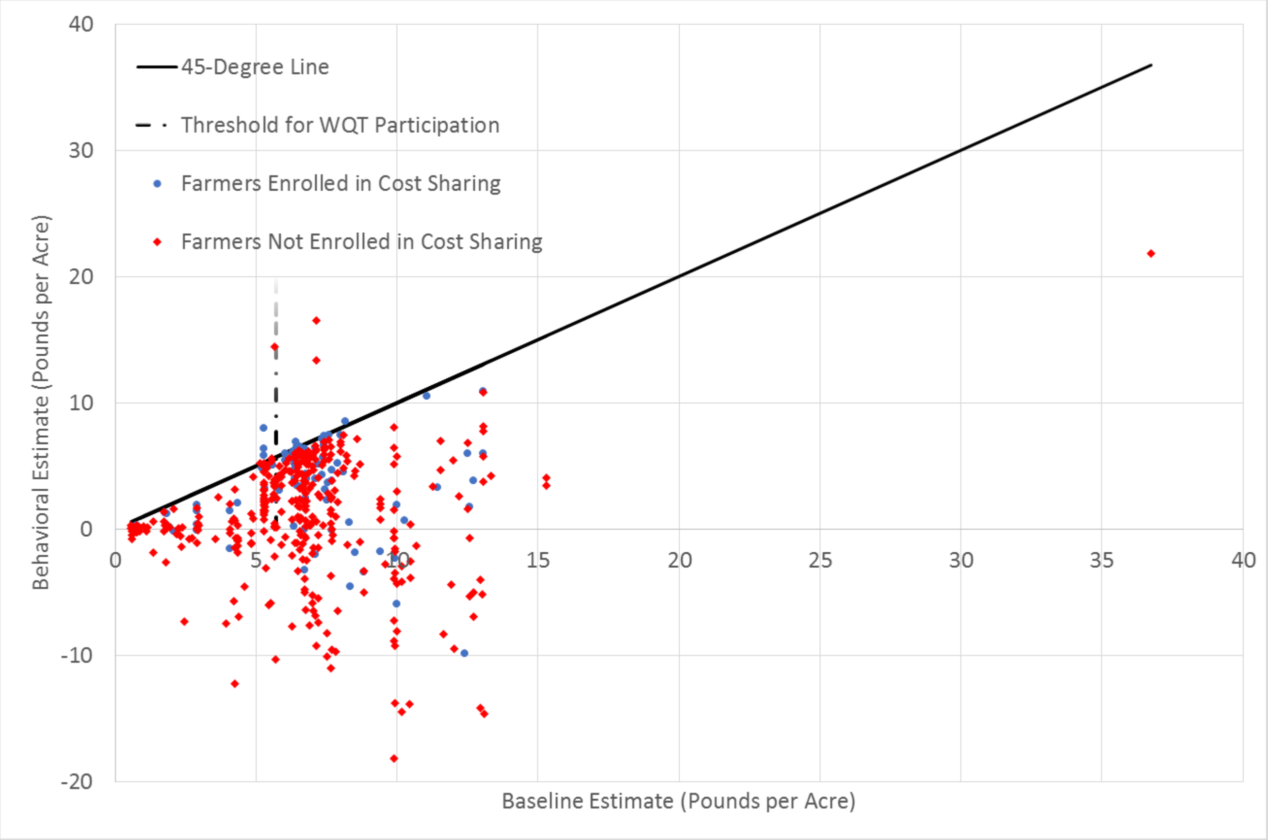


Figure 2. Behavioral versus Baseline Estimates of Nitrogen Emission Reductions from Cover Crop Adoption

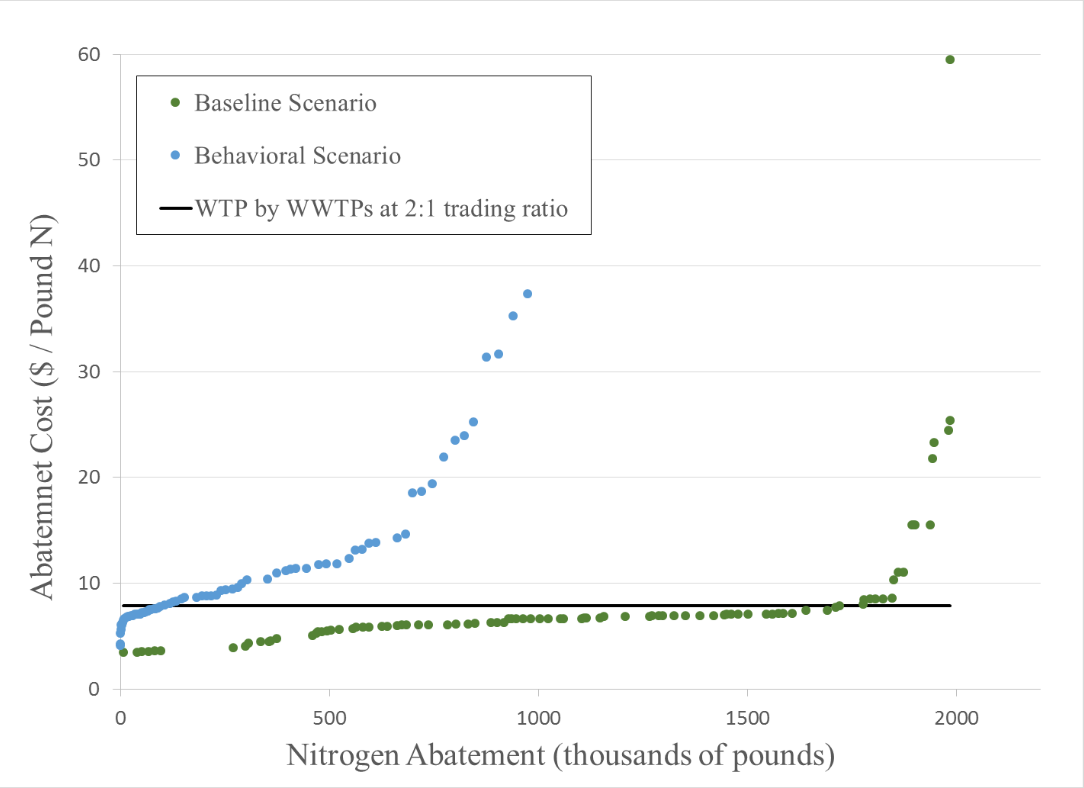


Figure 3. Supply Curve for Nitrogen Abatement by Farmers Enrolled in Cover Crop Cost Share Program

Tables

Table 1. Nitrogen Abatement and Cost-Effectiveness for Existing Cover Crop Cost Share (CS) Program (Prior to Introduction of Water Quality Trading Program)

	CS enrolled farmers
Total cover crop acreage enrolled	305,844
Total cost	$13,762,962
Baseline nitrogen abatement (lbs.)	1,984,963
Baseline average cost ($ / lb.)	$6.93
Behavioral nitrogen abatement (lbs.)	1,194,221
Behavioral average cost ($ / lb.)	$11.52

Notes:
Survey expansion factors provided by Maryland Agricultural Statistics Service (MASS) are used to derive population estimates.

Table 2. Nitrogen Abatement and Cost-Effectiveness of Water Quality Trading (WQT) Program and Cover Crop Cost Share (CS) Program

	Group 1 CS enrolled (stayers)	Group 2 WQT participant (prior CS enrolled)	Group 3 WQT participant (prior CS unenrolled)	Total
Total cover crop acreage	77,792	228,052	365,244	671,088
Total cost	$3,500,635	$13,596,256	$22,582,369	39,679,260
Baseline nitrogen abatement (lbs.)	263,917	1,721,045	2,858,528	4,843,490
Baseline average cost ($ / lb.)	$13.26	$7.90	$7.90	$8.19
Behavioral nitrogen abatement (lbs.)	175,608	1,018,613	1,281,200	2,475,420
Behavioral average cost ($ / lb.)	$19.93	$13.35	$17.63	$16.03

Notes:
The WQT Program models wastewater treatment plants (WWTPs) contracting with farms in exchange for the adoption of cover crops, at a 2:1 trading ratio. WWTPs are willing to pay no more than their own average cost of N abatement upgrades ($15.80 / lb., see Jones et al. 2010), which implies a payment to farms of no more than $7.90 / lb. at the 2:1 ratio. Modeled abatement is based on the Chesapeake Bay Program (CBP) watershed model. Survey expansion factors provided by Maryland Agricultural Statistics Service (MASS) are used to derive population estimates.
Group 1: MACS Enrolled, likely to remain in MACS
Group 2: MACS Enrolled, likely to switch into the WQT Program
Group 3: Not MACS Enrolled, but potential WQT participant

Appendix Tables

Appendix 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

Note.—N=445 for all variables.

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

Appendix 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)
	-0.0838*	-

Erosion benefit (tons reduced / $):	(0.0461)	
Cover crops		
Conservation tillage	-	-0.0233
		(0.0275)
Observations	445	445

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

Appendix 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.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.