

Water Quality Trading in the Presence of Conservation Subsidies

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ABSTRACT *Most studies of water quality trading analyze its cost-effectiveness in isolation from existing policies like conservation subsidy programs that pay farmers to use conservation practices. We investigate the interaction between trading and conservation subsidy programs using an integrated assessment model that combines farmer behavioral responses with a biophysical water quality model. Current subsidy program enrollees with comparative advantage in nitrogen abatement will sort into the trading program, worsening adverse selection. Actual increases in abatement from trading depend on incentivizing additional conservation practice acreage without inducing the conversion of vegetative cover to cropland. (JEL Q52, Q58)*

1. Introduction

Water quality trading 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 have high marginal abatement costs, gains from trading can be achieved when those point-source emitters purchase nutrient offset credits from low-cost nonpoint sources such as farmers who adopt conservation practices (Horan and Shortle 2005). It is estimated that the potential saving in compliance costs from expanded trading to meet total maximum daily load (TMDL) regulations could be \$1 billion or more annu-

ally (U.S. Environmental Protection Agency 2001). Water quality trading is also promoted as a mechanism that can help reduce costs associated with asymmetric information by revealing the opportunity costs of adoption and thereby providing the most cost-efficient outcomes for agricultural nutrient abatement (Rabotyagov, Valcu, and Kling 2013).

An implicit assumption in prior evaluations is that the effectiveness of trading can be analyzed in isolation. However, federal and state programs that subsidize farm conservation practices are the dominant source of incentives for nutrient abatement from agricultural sources and will likely remain so for the foreseeable future. Federal programs for subsidizing conservation practices on working farmland received sharply increased funding from 2002 onward, with \$4.2 billion allocated to farmers in fiscal year 2020 via the Environmental Quality Incentives Program, the Conservation Stewardship Program, and related programs (U.S. Department of Agriculture 2019). Many proposed trading programs enter into an existing policy landscape where conservation subsidy programs are already established. As a prospective analysis of trading programs, it is therefore essential to understand how agricultural nonpoint-source emitters may respond to the competing incentives provided under these two types of programs.

The introduction of market-based mechanisms into an existing policy environment has been known to create problems. Perhaps the most notable is the electricity sector, where cap-and-trade programs for carbon interact with preexisting policies such as renewable portfolio standards and feed-in tariffs, enacted to expand the production and use of renewable energy (see Fischer and Preonas [2010]

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for a survey). Theoretical and empirical simulation analyses show that renewable portfolio standard/feed-in tariff programs create incentives that clash with those created by cap-and-trade systems for carbon, resulting in reduced additionality (Tsao, Campbell, and Chen 2011) and, in some cases, perverse outcomes like the expansion of the dirtiest fossil fuels (e.g., coal) at the expense of cleaner ones (Bohringer and Rosendahl 2010).

This paper examines interactions between water quality trading and conservation subsidy programs. Our approach recognizes that participation in both types of programs is voluntary and thus may lead to adverse selection and other unintended behavioral responses. First, both programs may be subject to non-additionality. Funded conservation practices are nonadditional if they would have been implemented even in the absence of funding, a situation that occurs when private benefits exceed the costs of adoption (Horowitz and Just 2013). The empirical literature indicates that nonadditionality due to adverse selection can be large enough to constitute an economically meaningful share of adoption (e.g., Chabé-Ferret and Subervie 2013; Mezzatesta, Newburn, and Woodward 2013; Claassen, Duquette, and Smith 2018). Second, payments for conservation practices may make it profitable to expand or maintain crop production on marginal land that would be in vegetative cover were subsidy payments not available (Lichtenberg and Smith-Ramirez 2011). Drawing on the analogous phenomenon in land retirement programs, this outcome has been referred to as slippage in the existing literature.¹ Since emissions are generally lower on uncultivated land (e.g., pasture or

hay) than on land devoted to crop production, this effect can offset emissions reduction and increase the net cost of water quality improvements (Fleming, Lichtenberg, and Newburn 2018). Finally, receipt of a subsidy for one conservation practice can have indirect effects on the use of related practices. For example, practices with agronomic complementarities such as cover crops and conservation tillage (Balkcom et al. 2012) would be mutually reinforced by subsidy payments for either one of them (Fleming 2017). When accounting for these behavioral responses, actual nutrient reductions achieved can differ substantially from those reductions credited in either conservation subsidy or water quality trading programs.

We use an integrated assessment model to perform an ex ante analysis of the interaction of trading with existing conservation subsidies. The model is constructed from two sources: (1) the econometric model of farmers' response to conservation subsidies for planting cover crops and subsequent crop acreage decisions of Fleming, Lichtenberg, and Newburn (2018) and (2) the Chesapeake Bay program's watershed model. The econometric model by Fleming, Lichtenberg, and Newburn (2018) is used to generate farm-specific estimates of the direct effect of cover crop subsidy receipt on the share of the farm's acreage in cover crops, as well as potential indirect effects on conservation tillage and loss of vegetative cover. We link these three types of treatment effects to the Chesapeake Bay Program watershed model to estimate farm-level abatement of nitrogen loads delivered to the bay in response to conservation subsidy receipt.

We use this integrated assessment model to examine the farm-level cost-effectiveness for nitrogen abatement in the existing conservation subsidy program. We then analyze the likely effects of introducing a trading program containing features based on Maryland's proposed water quality trading program as an ex ante analysis of policy interactions. Our main purpose is to understand how farmers are likely to respond to the differing incentive structures

¹Note that the mechanism for slippage in a cost-sharing program on working lands is distinct from slippage due to land retirement programs (e.g., Conservation Reserve Program). The latter is argued to increase crop prices via supply restrictions, which indirectly induce previously marginal land in vegetative cover to be profitably converted to cropland (Wu 2000; Roberts and Bucholtz 2005). Cost-sharing payments create a direct incentive to expand crop production onto land that was previously more profitable in vegetative cover. When the government offers subsidies for cropland conservation practices such as cover crops, it increases the profitability of growing crops on marginal land that would be in vegetative cover in the absence of subsidy payments (Lichtenberg and Smith-Ramirez 2011, see discussion on

p. 116 and Figure 1 on p. 118). The loss of vegetative cover would be larger when the subsidy per acre is more generous.

in the trading and conservation subsidy programs. We develop a conceptual framework to show how profit-maximizing farmers currently enrolled in the subsidy program will choose between remaining in that program or switching to the trading program. We extend this framework to understand which farmers currently not enrolled in the conservation subsidy program may participate in trading. We then use the integrated economic-biophysical model to empirically evaluate the cost-effectiveness of nitrogen abatement when conservation subsidies are the only option, in comparison to a scenario in which both programs offer competing incentives for farmers.

Our analysis yields several main results. First, we show that farmers may switch from conservation subsidies to water quality trading because of a key difference in the incentive structure between the two programs: conservation subsidies pay on a per acre basis, while trading is conducted on a per pound of nutrient reduction basis. More generally, conservation subsidy programs pay for effort, while trading programs pay for performance. Farmers enrolled in the existing conservation subsidy program with comparatively higher nitrogen abatement will find selling offset credits in the trading program more profitable than remaining in the conservation subsidy program. As a result, introducing water quality trading worsens adverse selection and increases the average payment per pound of nitrogen abatement in the existing subsidy program. Second, farmers who switch from the conservation subsidy program to the trading program will now be paid more for the nitrogen abatement they had supplied prior to trading, as these farmers switch programs in order to obtain higher payments. Hence, the introduction of trading—a cost-effective policy when analyzed in isolation—will increase the total payments required to achieve the nutrient reductions previously obtained by conservation subsidies alone. Finally, any increase in water quality benefits from introducing trading comes primarily from farmers not currently enrolled in the conservation subsidy program who plant cover crops in order to sell offset credits. However, the cost-effectiveness of the nitrogen reductions provided by this group is substantially lower after accounting

for nonadditional adoption of cover crops and potential losses in vegetative cover (i.e., slippage effects). As a result, farm-level abatement costs for some farmers in this group are higher than the average expected cost of the point-source polluter upgrading internally. In those cases, offset credits from farmers planting cover crops are not the cost-saving alternative they are widely believed to be. In sum, while water quality trading has been promoted for decades for its potential cost savings and was even the primary example used by Dales (1968), who first proposed the idea of transferable discharge permits, the extent to which those savings materialize depends on interactions between trading and existing conservation subsidy programs.

2. Background

Despite extensive restoration efforts during the past 30 years, insufficient progress on water quality improvements in the Chesapeake Bay prompted the U.S. Environmental Protection Agency (EPA) to establish TMDL regulations in 2010. The bay's TMDL program 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, and 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 of water quality impairment, contributing 45% of nitrogen, 44% of phosphorus, and 65% of sediment loads entering the bay.²

Conservation subsidy 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. Each state in the Chesapeake Bay watershed uses conservation subsidies as a key policy tool for meeting its jurisdictions' TMDL goals. In Maryland, the Maryland Agricultural Water Quality Cost Share (MACS) program has been the principal source of

² See <https://tmdl.chesapeakebay.net/>.

funding for agricultural conservation practices that address officially recognized water quality problems, with state expenditures far in excess of federal cost-share spending. MACS has increasingly emphasized subsidy payments to farmers 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 severalfold 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 provided a base payment set at \$45 per acre in 2009 for traditional cover crops; that payment level has remained within a similar range of \$45 to \$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 requirements are substantial for regulated point and urban nonpoint (e.g., stormwater) sources. The Clean Water Act regulates point-source discharges from wastewater treatment plants, requiring compliance with National Pollution Discharge Elimination System permits. In 1987, the EPA also brought stormwater under its purview, mandating that large municipal separate storm sewer systems located in jurisdictions with populations of 100,000 or more must obtain and comply with the Clean Water Act's permit system. Estimated costs to comply with the 2025 Chesapeake Bay TMDL regulations 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 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 trading program in Maryland, established prior to the TMDL regulations in 2008, had no trades (Fisher-Vanden and Olmstead 2013). The primary reason is that wastewater treatment plants were not allowed to purchase offset credits but instead were required to install specific nutrient removal technologies (Van Houtven et al. 2012); likewise, municipal separate storm sewer system jurisdictions were not allowed to trade for stormwater management permits. After considerable planning and negotiation, the state of Maryland recently adopted revised water quality trading regulations in 2018 that allow treatment plants and municipal jurisdictions to purchase nutrient offset credits from agricultural sources.³ These revised rules, however, stipulate that nutrient offset credits can be used for only a portion of the National Pollution Discharge Elimination System 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 water quality trading program as an approach to lower the compliance cost for regulated point sources and to encourage additional abatement from agricultural nonpoint sources.

While there are no existing trades in Maryland to serve as a basis for empirical analysis (in the sense of *ex post* program evaluation of water quality trading), the subsidy payments provided in the MACS cover crop program provide insight into expected farmer responses to payments for the voluntary adoption of cover crops and related practices. The cover crop program operates essentially in a

³ See the Maryland Trading and Offset Policy and Guidance Manual: <http://mde.maryland.gov/programs/water/Documents/WQTAC/TradingManualUpdate4.17.17.pdf>.

manner similar to point/nonpoint-source trading. Participation in both water quality trading and the cover crop subsidy program is voluntary. Farmers who choose to participate in the MACS subsidy program receive a fixed payment per acre for adopting cover crops, while those farmers who plant cover crops in order to sell offset credits 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 water quality trading, and even after the Chesapeake Bay TMDL reduction implementation in 2025.⁴

Understanding interactions between competing incentives in water quality trading and conservation subsidy programs is important beyond the specifics of Maryland and the Chesapeake Bay. Although each water quality trading program has specific rules that vary according to regional authorities (see Fisher-Vanden and Olmstead [2013], Shortle [2013], and Stephenson and Shabman [2017] for reviews of existing water quality trading programs), all water quality trading programs enter into an existing landscape of federal and state conservation subsidy programs. Understanding how transferable discharge permit programs are likely to compete and interact with other incentives is therefore critical for policy design and implementation planning.

3. An Integrated Assessment Model for Water Quality

We construct an integrated assessment model by matching farm-specific effects of the Maryland conservation subsidy program, derived from the econometric model of Fleming, Lichtenberg, and Newburn (2018), with parameters from the Chesapeake Bay Program watershed model to calculate the nitro-

gen abatement from each farm. We begin with an overview of the econometric model from Fleming, Lichtenberg, and Newburn (2018) used to estimate farm-level treatment effects for the cover crop subsidy program. Then we describe the relevant Chesapeake Bay Program watershed model parameters and how these parameters are integrated with the farm-level treatment effects to generate farm-specific estimates of nitrogen abatement and associated costs per pound of nitrogen runoff reduction.⁵

Econometric Model

The econometric model applied to this analysis, from Fleming, Lichtenberg, and Newburn (2018), utilizes data from a survey of farmers drawn from the U.S. Department of Agriculture National Agricultural Statistics Service master list of farmers in Maryland. The survey asked farmers whether they had implemented certain conservation practices, acreage in each practice, whether cost-sharing subsidies were received from any state or federal program, and other characteristics of the farmer and farm operation in 2009. The survey was implemented by mail with telephone follow-up, administered by the Maryland office of the National Agricultural Statistics Service in the spring of 2010. Stratified random sampling was used to ensure sufficient response from large operations, and expansion factors were provided for deriving statewide population estimates.

The econometric analysis from Fleming, Lichtenberg, and Newburn (2018) focuses on cover crop subsidies, which have been the centerpiece of Maryland's efforts to combat agricultural nitrogen runoff into Chesapeake Bay. The econometric model focuses on three

⁴Some jurisdictions have integrated aspects of the administration of conservation subsidy and water quality trading 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).

⁵While the Chesapeake Bay TMDL program 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 Chesapeake Bay states (Kaufman et al. 2014).

outcomes: (1) cover crop acreage, (2) acreage cultivated using conservation tillage, and (3) acreage in vegetative cover (hay, pasture, and other forms of vegetative cover).

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 (Fleming 2017; Fleming, Lichtenberg, and Newburn 2018). Cover crop subsidies come primarily from MACS, while subsidies for conservation tillage come primarily from federal programs.

Receipt of payments for conservation practices can make it profitable for farmers to begin cultivating some land previously in hay, pasture, or other forms of vegetative cover. Since nitrogen runoff from land in vegetative cover is lower than runoff from land cultivated for crops, conversion of vegetative cover to cropland will offset some of any reduction in nutrient runoff obtained from the expansion of conservation practice use (see Lichtenberg and Smith-Ramirez [2011] for formal arguments).

The econometric model is a switching regression with endogenous switching (see Fleming, Lichtenberg, and Newburn 2018). It is estimated in two stages using a control function approach to control for self-selection (Wooldridge 2014). The first stage estimates voluntary enrollment in the Maryland cover crop subsidy program and the conservation tillage subsidy program using a bivariate probit model with explanatory variables that include farm and farmer characteristics. The second stage estimates the acreage share in cover crops, conservation tillage, and vegetative cover in a trivariate tobit model. Measures of water quality impacts that influence agency decisions but not farm profitability are used as instruments to identify conservation subsidy program enrollment. Those measures include distance to the nearest surface water body and whether the farm is adjacent to the

Chesapeake Bay. MACS and other conservation subsidy programs use such indicators to evaluate potential water quality impacts of conservation practice implementation; distance to the nearest surface water is included in MACS application forms, for instance. A farm's proximity to surface water does not affect private benefits of cover crop or other conservation practice use, such as reductions in erosion and improvements in soil quality. Statistical tests indicate that these instruments are correlated with conservation subsidy receipt but not with acreage in cover crops, conservation tillage, or vegetative cover (see Fleming, Lichtenberg, and Newburn 2018).

The econometric model is used to estimate acreage shares for each of the three practices $k = \{\text{cover crops, conservation tillage, vegetative cover}\}$ with and without receipt of cover crop subsidy payments for each individual farmer i . Let the superscript $m = \{1,0\}$ indicate with and without enrollment in the cover crop program, respectively. 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 . Then the farm-level treatment effects on the treated (TET) are calculated for each enrolled farmer and conservation practice as

$$\widehat{TET}_{ik} = \hat{s}_{ik}^1 - \hat{s}_{ik}^0, \quad [1]$$

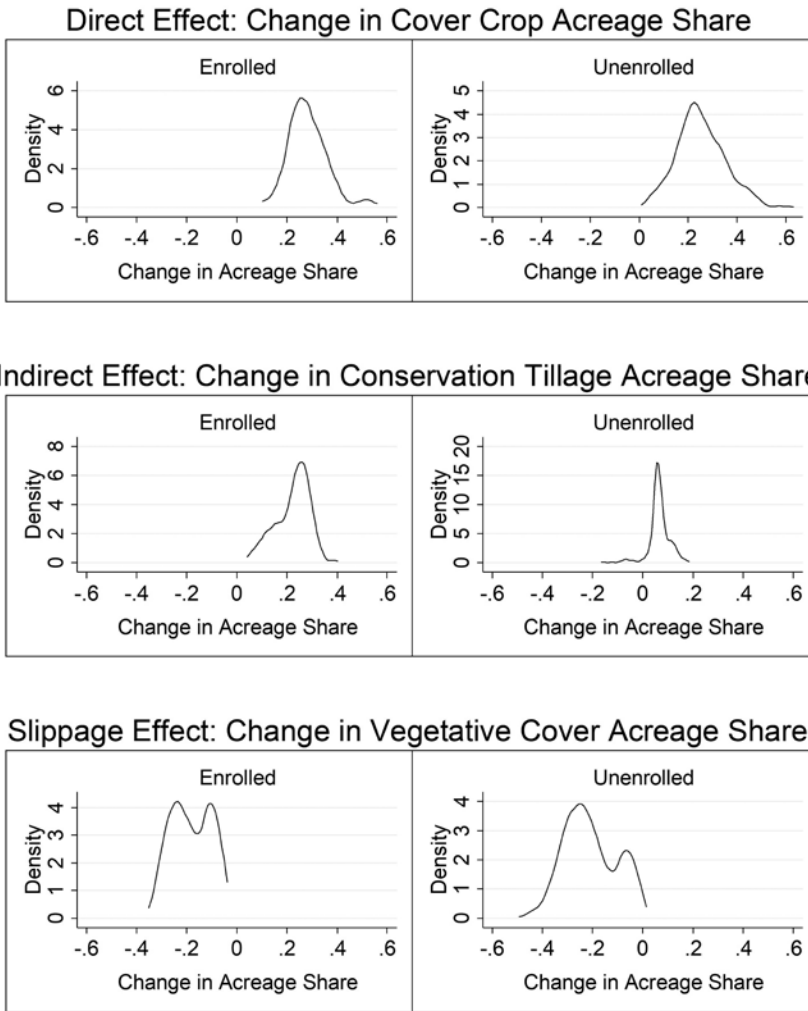
where $i \in I^1$ for the set of enrolled farmers.

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

$$\widehat{TEU}_{ik} = \hat{s}_{ik}^1 - \hat{s}_{ik}^0, \quad [2]$$

where $i \in I^0$ for the set of unenrolled farmers. Note that for enrolled farmers, the value \hat{s}_{ik}^0 is the estimated counterfactual acreage share in practice k if a farmer had *not* enrolled in the conservation subsidy program. This counterfactual estimate is obtained by combining the parameter estimates from the unenrolled group with the enrolled farmer's observed covariates X_i . Similarly, \hat{s}_{ik}^1 is the counterfactual acreage share among unenrolled farmers, representing the expected acreage share in practice k if the farmer had been enrolled in the subsidy program.

Figure 1
Distribution of Farm-Level Treatment Effects on Acreage Shares due to Conservation Subsidy Receipt



Three treatment effects are estimated for each farmer. The direct effect estimates the change in cover crop acreage share due to cover crop subsidy receipt, adjusted for self-selection. The indirect effect estimates the change in conservation tillage acreage due to cover crop subsidy receipt. Consistent with the agronomic literature, this effect is positive because of the complementarities between these practices (Balkcom et al. 2012). The indirect effect thus indicates crowding-in of a complementary practice. Finally, the slippage effect reflects the loss in vegetative cover acreage due to cover crop subsidy receipt.

Figure 1 shows the distribution of treatment effects of conservation subsidy receipt for the three practices, as estimated using equations [1] and [2] for enrolled and unenrolled farmers, respectively (derived from Epanechnikov kernel functions). The average direct effect of conservation subsidy receipt is roughly the same for farmers currently enrolled in the subsidy program and those who are not. The distribution of direct effects is somewhat more dispersed for the currently unenrolled than for the currently enrolled. The indirect effect of conservation subsidy receipt shows more differences between the currently enrolled and

unenrolled. The indirect effect is generally positive for both groups, but larger on average for the currently enrolled than the unenrolled. The indirect effect is uniformly positive for the currently enrolled but negative for some of the currently unenrolled. Finally, the distribution of slippage effects (changes in vegetative cover) is bimodal for both enrolled and unenrolled farmers. The two peaks are due largely to whether grazing animals are present on the farm. The distribution of slippage effects is more dispersed for the currently unenrolled than for the currently enrolled. The slippage effect is also somewhat larger on average for the unenrolled than for the enrolled farmers.

Simulating Nitrogen Abatement from the Existing Cover Crop Program

The three sets of parameters from the Chesapeake Bay Program watershed model that we utilize are nitrogen loads, practice efficiencies, and delivery ratios. First, let L_z^{Crop} and L_z^{Veg} represent the nitrogen loads in pounds per acre for cropland and vegetative cover, respectively.⁶ These loads vary by river segment z in the Chesapeake Bay watershed model. Second, let e_k be a conservation practice efficiency 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 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, as described below. Third, let d_z be the delivery ratio 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 Chesapeake Bay Program watershed model parameters with the surveyed treatment effects, we calculate weighted-average loads and delivery ratios at the zip code level, allowing us to match the watershed model parameters with each farm. Nitrogen 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 conservation subsidy program for enrolled farmers under two scenarios. First, the perfect-additionality scenario assumes all cover crop acreage is entirely attributable to the cover crop subsidy program (i.e., no cover crop acreage would have been adopted without program payments), and ignores the indirect and slippage 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 the slippage or indirect effects. In this case, the perfect-additionality scenario assumes that the farm’s acreage share in cover crops without enrollment \hat{s}_{ik}^0 is zero. Letting A_i represent the operating acreage of each farm, nitrogen abatement in pounds under this scenario is calculated for enrolled farmer i as

$$\Delta N_i^{Perfect} = A_i \cdot \hat{s}_{ik}^1 \cdot L_i^{Crop} \cdot e_k \cdot d_i, \tag{3}$$

where $k = cover\ crops$.

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

$$\Delta N_i^{Direct} = A_i \cdot \widehat{TET}_{ik} \cdot L_i^{Crop} \cdot e_k \cdot d_i,$$

where $k = cover\ crops$;

$$\Delta N_i^{Indirect} = A_i \cdot \widehat{TET}_{ik} \cdot L_i^{Crop} \cdot e_k \cdot d_i,$$

where $k = conservation\ tillage$; and

$$\Delta N_i^{Slippage} = A_i \cdot \widehat{TET}_{ik} \cdot (L_i^{Crop} - L_i^{Veg}) d_i, \tag{4}$$

⁶The Chesapeake Bay Program 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.

where $k = \text{vegetative cover}$. Total abatement for the behavioral scenario, $\Delta N^{\text{Behavioral}}$, is then the sum of these three effects

$$\Delta N_1^{\text{Behavioral}} = \Delta N_1^{\text{Direct}} + \Delta N_1^{\text{Indirect}} + \Delta N_1^{\text{Slippage}}. \quad [5]$$

We scale up the farm-level estimates of nitrogen abatement to the statewide level in both the perfect-additionality and behavioral scenarios using survey expansion factors, ω_i , provided by the National Agricultural Statistics Service for deriving statewide population estimates. Total abatement obtained by the conservation subsidy program in the perfect-additionality scenario is then calculated as $Q^{\text{Perfect}} = \sum_i \Delta N_i^{\text{Perfect}} \cdot \omega_i$, where $i \in I^1$ for the set of enrolled farmers. Total abatement in the behavioral scenario is similarly calculated as $Q^{\text{Behavioral}} = \sum_i \Delta N_i^{\text{Behavioral}} \cdot \omega_i$, where $i \in I^1$.

In the case of slippage, when loss of vegetative cover occurs with the receipt of cover crop subsidy 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. Thus, the behavioral scenario tends to have lower nitrogen abatement than the perfect-additionality scenario, due to slippage as well as the nonadditional adoption of cover crops reflected in the direct effect. We compare the behavioral and perfect-additionality scenarios to understand the magnitude of the water quality impacts of behavioral responses in the conservation subsidy program and other programs with voluntary enrollment, such as trading.

We calculate total conservation subsidy 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 nonadditional acreage, nor do they account for potential slippage or indirect effects, the expected program costs are the same in both the perfect-additionality and the behavioral scenarios, based on cover crop acreage with program enrollment, \hat{s}_{ik}^1 . Specifically, the expected conservation subsidy payment c_i is calculated for each enrolled farmer as

$$c_i = A_i \cdot \hat{s}_{ik}^1 \cdot r, \quad [6]$$

where $k = \text{cover crops}$.

To estimate statewide conservation subsidy expenditures, we scale the farm-level payments shown in equation [6] by the survey expansion factors ω_i . We then sum these weighted payments across each enrolled farm in the sample, $TC = \sum_i c_i \cdot \omega_i$, where $i \in I^1$. TC is the total expected conservation subsidy expenditure to achieve the nitrogen abatement shown in the perfect-additionality and behavioral scenarios. Average nitrogen abatement costs per pound are calculated as TC/Q^{Perfect} and $TC/Q^{\text{Behavioral}}$ in the perfect-additionality and behavioral scenarios, respectively. Due to reduced vegetative cover and nonadditional cover crop adoption, average nitrogen abatement costs are expected to be higher in the behavioral scenario.

4. Conceptual Framework for Farmer Participation Decisions

We use the following simplified decision model to examine how a profit-maximizing farmer would choose among a newly introduced trading program, the existing conservation subsidy program, or neither. As before, let r denote the per acre payment offered in the conservation subsidy 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 conservation subsidy program. The net returns of participating in the subsidy program must be positive for each farmer who is already enrolled, such that

$$r - t_i^{\text{cs}} + (\mu_i - \eta_i) > 0 \quad \forall i \in I^1. \quad [7]$$

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

$$r - t_i^{\text{cs}} + (\mu_i - \eta_i) \leq 0 \quad \forall i \in I^0. \quad [8]$$

Now consider the introduction of a water quality trading program that contains features similar to the one recently proposed in Maryland. The key difference in the incentive structure between the conservation subsidy

and trading programs is that the conservation subsidy 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 point-source emitters, and let ζ denote the nonpoint/point-source trading ratio in the trading program. A value of ζ greater than 1 indicates that larger quantities of nonpoint-source nitrogen reduction are required for each pound of point-source reduction, a feature of nutrient trading based on the uncertainty of modeled nonpoint-source abatement. Thus, as ζ increases, the profitability of trading decreases for farmers. Let $h_i(s_{ik}^*, z)$ denote the per acre reduction in nitrogen emissions, given the optimal choice of cover crop acreage ($k = \text{cover crops}$) for farmer i located in river segment z . Note that the value of h_i will correspond to per acre abatement in the perfect-additionality scenario ($\Delta N_i^{\text{Perfect}}/A_i$) for purposes of determining credits in a water quality trading program. There is asymmetric information because the agency managing the trading program observes only the enrolled acreage in cover crops but not the behavioral responses of farmers.

We assume that all farms meet baseline requirements for nutrient reductions imposed by regulatory authorities and are thus eligible to trade any nutrient credits generated with cover crop adoption. Further, any farmer enrolled in the conservation subsidy program is not eligible to use the same practice to generate offset credits for sale in the trading 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 $t_i^{\text{CS}} \approx t_i^{\text{WQT}} \approx t_i$. Accordingly, net returns for cover crop adoption in order to sell credits in the proposed water quality trading program may be expressed as

$$\frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i). \tag{9}$$

Upon introduction of the trading program in the context of the existing conservation subsidy program, there are four relevant groups into which farmers sort based on the relative

profitability of the two programs. Consider first a farmer currently enrolled in the conservation subsidy program. The farmer will remain in the conservation subsidy program if the net returns are greater than or equal to those from selling offset credits.

$$\begin{aligned} \text{Group 1: } & r - t_i + (\mu_i - \eta_i) \geq \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i \\ & + (\mu_i - \eta_i), \\ \text{or } & h_i(s_{ik}^*, z) \leq \frac{\zeta r}{\theta}, \forall i \in I^1. \end{aligned} \tag{10}$$

We refer to farmers in Group 1 as Stayers.

In contrast, a farmer currently enrolled in the conservation subsidy program will switch into the trading program to sell offset credits if the net returns from selling offset credits are greater than the net returns for remaining in the conservation subsidy program.

$$\begin{aligned} \text{Group 2: } & \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i) > r - t_i \\ & + (\mu_i - \eta_i), \\ \text{or } & h_i(s_{ik}^*, z) > \frac{\zeta r}{\theta}, \forall i \in I^1. \end{aligned} \tag{11}$$

We refer to farmers in Group 2 as Switchers. For the conservation practice acreage previously enrolled in the subsidy program, the reduction in nitrogen emissions obtained from the sale of offset credits by Switchers will equal the reduction in nitrogen emissions for enrollment in the conservation subsidy program. In these cases, trading will increase payments without achieving any corresponding increases in nitrogen reduction.

Note that the ratio $\zeta r/\theta$ represents the threshold of abatement in pounds per acre that determines the relative profitability of the conservation subsidy and water quality trading programs. Farms with abatement per acre h_i above this threshold will receive greater returns by selling offset credits than by enrolling in the conservation subsidy program, and vice versa.

Now consider the impact of introducing water quality trading to farmers who are not currently enrolled in the conservation subsidy program. Currently unenrolled farmers will find it profitable to trade offset credits if

$$\text{Group 3: } \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i) > 0 \geq r - t_i + (\mu_i - \eta_i). \tag{12}$$

The first inequality indicates that trading results in positive net returns. Meanwhile, the second inequality indicates that the net returns for enrollment in the conservation subsidy program are known to be less than or equal to zero, given the farmer is not currently enrolled (see condition [8]). Since farmers who satisfy condition [12] will be new recipients of payments for nutrient reduction, we refer to this group as Joiners.

In the absence of data on individual farmer transaction costs and net private returns of cover crop adoption, we simplify condition [12] to the following decision rule that characterizes currently unenrolled farmers who may sell offset credits in the trading program:

$$h_i(s_{ik}^*, z) > \frac{\zeta r}{\theta}, \quad i \in I^0. \tag{13}$$

Note that condition [13] will hold for some farmers for whom cover crop planting is unprofitable under either water quality trading or conservation subsidy program enrollment (specifically, those for whom $0 \geq \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i) > r - t_i + (\mu_i - \eta_i)$). Thus, condition [13] represents an upper bound of trading program participation among unenrolled farmers.

Finally, a fourth group of farmers who are not currently enrolled in the conservation subsidy program will also not sell offset credits in the trading program. For these farmers, the net returns from either trading or conservation subsidies are negative or zero.

$$\text{Group 4: } 0 \geq r - t_i + (\mu_i - \eta_i) \geq \frac{\theta}{\zeta} h_i(s_{ik}^*, z) - t_i + (\mu_i - \eta_i). \tag{14}$$

We refer to this group as Nonparticipants since these farmers participate in neither program. Once again, in the absence of data on individual farm-level transaction costs and private returns from cover crop adoption, we characterize unenrolled farmers who will not sell offset credits by the following simplified condition:

$$h_i(s_{ik}^*, z) \leq \frac{\zeta r}{\theta}, \quad \forall i \in I^0. \tag{15}$$

Just as condition [13] represents an upper bound on program participation in trading to sell offset credits, condition [15] correspondingly represents a lower-bound estimate of farms that will not sell offset credits in the water quality trading program.

In keeping with the preceding discussion, we estimate nitrogen abatement for water quality trading under the assumption that farmers who are currently not enrolled in the conservation subsidy program will sell offset credits in the trading program if $h_i(s_{ik}^*, z) > \zeta r / \theta$. The extent to which our procedure overestimates offset credit sales and thus incremental nitrogen runoff reduction from trading depends on the ratio of the cover crop payment to the offset credit price. We therefore conduct sensitivity analysis to assess how our results are affected by different assumptions related to this relative price threshold.

Our baseline parameterization of the model is as follows. We assume that the equilibrium price equals the cost of upgrading a wastewater treatment plant, which in our study region has been estimated to be $\theta = \$15.80$ per pound of nitrogen (Jones et al. 2010).⁷ We assume a nonpoint:point-source trading ratio $\zeta = 2$, as specified in the proposed Maryland trading regulations for trades between wastewater treatment plants and the agricultural sector. We do not adjust abatement from wastewater treatment plants for delivery ratios to the Chesapeake Bay.⁸ 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 farm-level abatement h_i when determining the sorting of a farm between the trading and conservation subsidy programs. The trading program managers apply the perfect-additionality scenario estimates, $h_i = \Delta N_i^{\text{Perfect}} / A_i$, for nitrogen abatement when evaluating the num-

⁷Note that \$15.80 represents an upper bound on the willingness to pay by a wastewater treatment plant in the region. Treatment plants 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.

⁸Many large wastewater treatment plants in Maryland are located adjacent to the bay and thus have a delivery load factor $d = 1$.

ber of credits that a given farmer generates with cover crop adoption. Farmers currently enrolled in the conservation subsidy program with modeled abatement less than 5.7 pounds per acre will remain in the program (Stayers), while those with abatement greater than 5.7 pounds per acre may switch to the trading program to sell nutrient offset credits (Switchers). Farmers currently not enrolled in the conservation subsidy program with modeled abatement less than 5.7 pounds per acre will participate in neither program (Nonparticipants), while current nonenrollees may potentially choose to sell nutrient offset credits if their modeled cover crop 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 $\Delta N_i^{\text{Perfect}}$ by the effective credit price of \$7.90 per pound, given the trading ratio, ζ . Specifically, the expected water quality trading program cost c_i^{wqt} for farmer i in Groups 2 and 3 is calculated as

$$c_i^{\text{wqt}} = \Delta N_i^{\text{Perfect}} \cdot \theta / \zeta. \tag{16}$$

For currently unenrolled farms such as those in Group 3, modeled emissions reductions $\Delta N_i^{\text{Perfect}}$ are derived from the estimates of cover crop acreage in the counterfactual scenario of program enrollment, as shown in equation [2].⁹

We calculate total statewide costs of the water quality trading program by scaling these farm-level costs with the expansion factors ω_i , similar to the approach above for calculating the statewide cost for the conservation subsidy program. Specifically, $TC^{\text{CS}} = \sum_i c_i^{\text{CS}} \cdot \omega_i$, where i is separately summed for the subset of farmers in Group 1, and $TC^{\text{wqt}} = \sum_i c_i^{\text{wqt}} \cdot \omega_i$, where i is separately summed for the subset of farmers in Group 2 and Group 3, respectively. The average abatement costs in the conservation subsidy program for Group 1 are calculated in the same way as discussed in the

preceding section for the existing 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 water quality trading program in the perfect-additionality scenario, $TC^{\text{wqt}} / Q^{\text{Perfect}}$, are equal by definition to the per pound cost of credits, since $Q^{\text{Perfect}} = \sum_i \Delta N_i^{\text{Perfect}} \cdot \omega_i$, leading to the expression

$$\begin{aligned} TC^{\text{wqt}} / Q^{\text{Perfect}} &= \left(\frac{\sum_i c_i^{\text{wqt}} \cdot \omega_i}{\sum_i \Delta N_i^{\text{Perfect}} \cdot \omega_i} \right) \\ &= \left(\frac{\sum_i \Delta N_i^{\text{Perfect}} \cdot \theta / \zeta \cdot \omega_i}{\sum_i \Delta N_i^{\text{Perfect}} \cdot \omega_i} \right) = \frac{\theta}{\zeta}, \end{aligned} \tag{17}$$

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

$$\begin{aligned} TC^{\text{wqt}} / Q^{\text{Behavioral}} &= \left(\frac{\sum_i c_i^{\text{wqt}} \cdot \omega_i}{\sum_i \Delta N_i^{\text{Behavioral}} \cdot \omega_i} \right) \\ &= \left(\frac{\sum_i \Delta N_i^{\text{Perfect}} \cdot \theta / \zeta \cdot \omega_i}{\sum_i \Delta N_i^{\text{Behavioral}} \cdot \omega_i} \right) \\ &= \frac{\theta}{\zeta} \left(\frac{Q^{\text{Perfect}}}{Q^{\text{Behavioral}}} \right). \end{aligned} \tag{18}$$

The relative difference between average abatement costs incurred by the trading program in the perfect-additionality and behavioral scenarios in equations [17] and [18] demonstrates the extent to which the perfect-additionality 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 conservation subsidy program alone prior to the introduction of water quality trading. The aim is to evaluate the current effectiveness of conservation subsidies for nutrient abatement when considering behavioral responses relative to perfect-additionality estimates. We then discuss how the introduction of a prospective water quality trading program is expected to interact with the existing con-

⁹Note that the econometric model derives the counterfactual cover crop acreages for currently unenrolled farmers— $\hat{s}_{ik}^1 \forall i \in I^0$ —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.

ervation subsidy program, in order to assess which farmers would sort into water quality trading versus the conservation subsidy program. We then summarize the implications for the cost-effectiveness and actual nitrogen abatement of both programs. Finally, we include a sensitivity analysis to show how our results are affected by different nutrient offset prices and trading ratios in the water quality trading program.

Conservation Subsidy Program Prior to Introduction of Trading

When only the conservation subsidy program is available, statewide cover crop acreage enrolled is estimated to be 305,884 acres, with corresponding expenditures of \$13.8 million. Under the perfect-additionality 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 perfect-additionality estimate. The average cost of nitrogen abatement is \$6.93 per pound under the perfect-additionality scenario but about two-thirds higher (\$11.52 per pound) when behavioral adjustments are considered.

Figure 2 compares the nitrogen abatement per acre of cover crops for the perfect-additionality and behavioral estimates. The *x*-axis shows nitrogen abatement per acre of cover crops in the perfect-additionality scenario, and the *y*-axis shows the same estimate in the behavioral scenario. Farmers currently enrolled in the conservation subsidy program exhibit considerable heterogeneity. It is noteworthy that nitrogen abatement on most farms lies below the 45-degree line, indicating that the behavioral responses of nonadditionality and reduced vegetative cover decrease the nitrogen abatement achieved with cover crop planting relative to perfect-additionality 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 effect 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 perfect-additionality and behavioral scenarios. The *x*-axis shows cumulative nitrogen abatement from cover crop planting in Maryland (using survey weights for deriving population estimates), and the *y*-axis shows marginal nitrogen abatement costs for each farm surveyed. A comparison of the two estimated abatement supply curves shows that, once behavioral responses of farmers are considered, marginal abatement costs are substantially higher than the perfect-additionality estimates at all levels of cumulative abatement. It is important to note that the supply curves in Figure 3 include only farms with positive levels of abatement cost per pound and exclude the subset of farmers with negative estimated 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 two scenarios.

Interactions between Conservation Subsidy and Water Quality Trading Programs

The conservation subsidy and water quality trading programs differ fundamentally in terms of incentive payment structure, with the conservation subsidy program paying per acre, while trading pays per pound of nitrogen reduction for cover crop planting calculated according to the Chesapeake Bay Program watershed model. That distinction implies that farmers currently enrolled in the conservation subsidy program with comparatively higher nitrogen abatement will sort into the trading program, while current conservation subsidy program enrollees with lower nitrogen abatement levels will remain in the subsidy program, as shown in conditions [10] and [11] above. Under the parameterization of our model, the threshold for this sorting occurs at a perfect-additionality estimate of 5.7 pounds per acre, indicated by the vertical line in Figure 2. Farmers currently enrolled in the conservation subsidy program may participate in the trading program if their modeled abatement lies to the right of this vertical line (Switchers), while current enrollees with nitrogen abatement lying to the left of the ver-

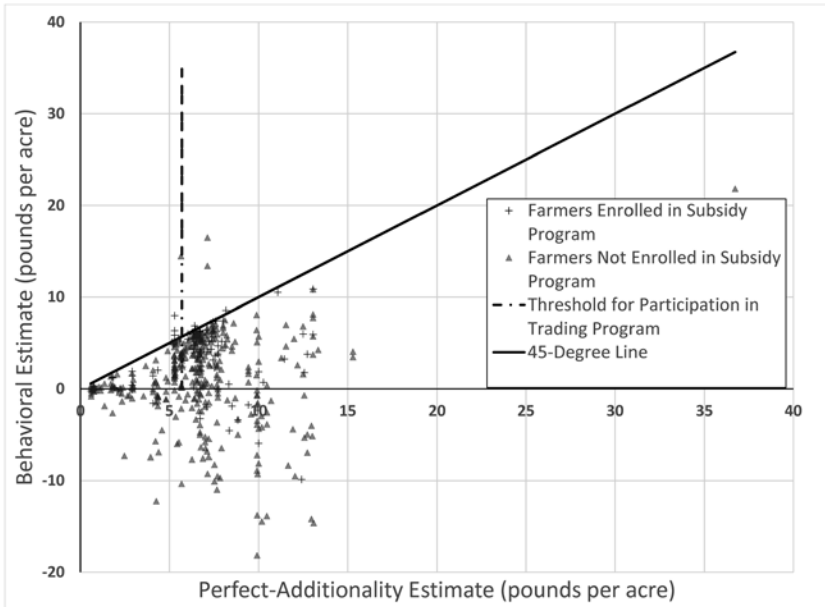
Table 1
Nitrogen Abatement and Cost-effectiveness with and without Water Quality Trading Program

	Conservation Subsidies Only		Conservation Subsidy and Water Quality Trading Programs Both Available		
	Current Conservation Subsidy Enrollees (1)	Stayers: Current Enrollees Remaining in Conservation Subsidy Program (2)	Switchers: Current Enrollees Switching to Water Quality Trading Program (3)	Joiners: Current Nonenrollees Potentially Selling Credits in Water Quality Trading Program (4)	Total for Both Programs (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
Perfect-Additionality 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

Notes: Column (1) displays the estimated enrollment of cover crops in the conservation subsidy program prior to the introduction of trading, along with associated program costs and nitrogen abatement. Nitrogen abatement is calculated for two scenarios: (1) a perfect-additionality scenario that assumes all cover crop acreage paid for by the program would not have been planted otherwise and ignores potential indirect effects on conservation tillage and loss of vegetative cover; and (2) a behavioral scenario that accounts for nonadditional adoption of cover crops, as well as potential indirect effects and loss of vegetative cover. Columns (2) through (5) show the effects of the trading and conservation subsidy programs when both incentive options are available. Column (2) displays estimated cover crop enrollment, program costs, and nitrogen abatement associated with the group that remains in the conservation subsidy program. Column (3) displays the same information for the group switching into the trading program. Column (4) displays the upper bound on trading participation among farmers currently not enrolled in the conservation subsidy. Column (5) is the sum of cover crop enrollment, program costs, and modeled nitrogen abatement when both programs are available.

Figure 2

Behavioral and Perfect-Additionality Estimates of Nitrogen Emission Reductions from Cover Crop Adoption



tical line will remain in the conservation subsidy program (Stayers).

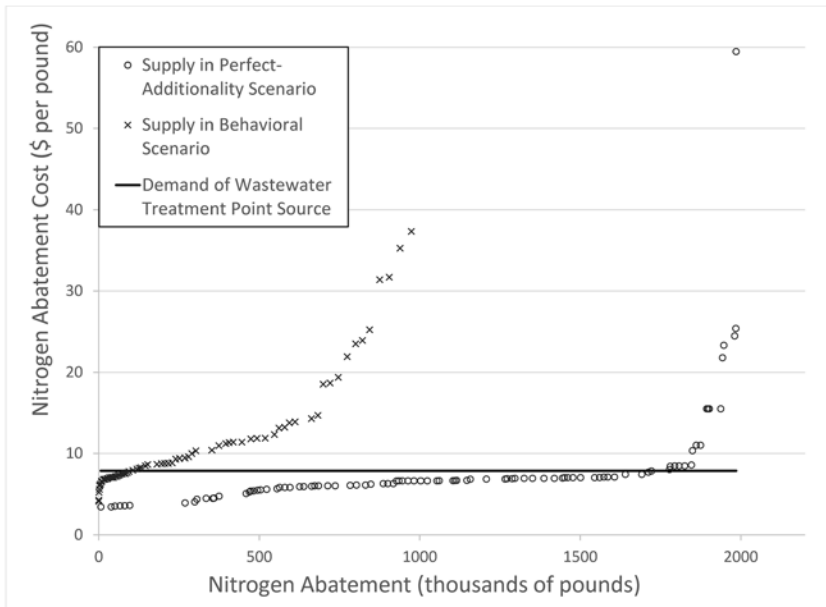
Figure 3 depicts the sorting of current conservation subsidy program enrollees into Stayers and Switchers using a supply-demand framework. The horizontal line depicts demand for offset credits at the average cost of \$7.90 per pound, representing the purchase of credits by wastewater treatment plants with average cost of internal upgrades at \$15.80 per pound (Jones et al. 2010) and a nonpoint/point-source trading ratio at 2:1. Current conservation subsidy program enrollees that have low marginal abatement costs below the horizontal demand curve would sort into the trading program (Switchers), while those with higher marginal abatement costs would remain in the cover crop program (Stayers).

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 conservation subsidy and water quality trading programs. As expected, average payments for nitrogen abatement among those remaining in the conservation subsidy program (Stayers) are higher,

as shown in column (2), in comparison to the existing conservation subsidy program in the absence of trading, as shown in column (1). Using the behaviorally adjusted estimates, average costs in the conservation subsidy program increase by 73% (from \$11.52 to \$19.93 per pound) as a result of the most cost-effective conservation subsidy program enrollees switching to the trading program. While the specific sorting threshold will vary in different regions, generally the adverse selection problem in conservation subsidy programs will be exacerbated upon the introduction of trading. Intuitively, this worsening of adverse selection occurs because the trading program attracts current subsidy recipients with the greatest comparative advantage in abatement and thus the lowest marginal abatement costs (and correspondingly greater ability to profit from trading).

A second unintended consequence is worth noting. Farmers who are enrolled in the conservation subsidy program and are cannibalized by the trading program now receive higher average nitrogen abatement payments, at \$13.35 per pound, in column (3) of Table 1, compared to the existing subsidy program, in

Figure 3
Supply Curves for Nitrogen Abatement in Proposed Trading Program among Farmers Currently Enrolled in Cover Crop Subsidy Program



column (1). The reason is that, prior to trading, the conservation subsidy program was the only option for high-abatement farms. When the trading and subsidy programs compete, however, these cost-effective farmers pursue larger payments by switching to trading offset credits. Specifically in Table 1, the existing conservation subsidy program achieves statewide nitrogen abatement of 1.19 million pounds for the behavioral scenario, at a total cost of \$13.8 million. The same farmers (Switchers and Stayers) achieve this level of abatement at a combined program cost of \$17.1 million following trading. That is, total expenditures increased by 24% following the introduction of trading while achieving the same water quality benefit. Once again, the magnitude of this cost increase will vary according to the threshold for switching implied by the specific characteristics of conservation subsidy and trading programs. Yet regardless of the specific threshold for switching between program types, the main result holds that combined program costs increase, despite the theoretical cost-effectiveness of trading as

a policy instrument when analyzed in isolation.

Finally, the estimates of potential participation in water quality trading from farmers currently not enrolled in the conservation subsidy program—shown in column (4) of Table 1—represent an upper bound on 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 prospective trading program. However, Joiners exhibit a much higher level of nonadditional adoption and reduced vegetative cover than the Stayers and Switchers (see Figure 2). As a result, estimated nitrogen abatement adjusted for farmer behavioral effects is only 45% of the perfect-additionality estimate. The average cost of nitrogen abatement correspondingly increases to \$17.63 per pound, or more than double the average cost of \$7.90 per pound. In fact, this average payment for nitrogen abatement from the Joiners—once adjusted for nonadditionality, indirect effects, and slippage effects for loss of vegetative cover—now exceeds the average

cost of internally upgrading treatment plants 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.

Sensitivity Analysis and Discussion

In this section, we explore how our results are affected by characteristics of the water quality trading program. In particular, we examine how changes in the cost of point-source upgrades and the nonpoint/point-source trading ratio—which together determine the equilibrium offset credit price—will affect the average cost of nitrogen abatement in the behavioral scenario, among the three relevant groups of farmers choosing between the subsidy and trading programs.

Consider first the cost of point-source upgrades. The demand for credits will depend on the upgrade costs faced by point-source emitters to remove nitrogen internally, which may be different than the \$15.80 per pound from Jones et al. (2010) described above in the context of wastewater treatment plants. New advances in technologies may lower the cost of nitrogen abatement by the likely purchasers of offset credits. Another recent estimate of the average abatement cost from enhanced nutrient reduction upgrades at wastewater treatment plants in Maryland implies annualized costs of \$9.97 per pound of nitrogen reduction in constant 2010 dollars, suggesting an equilibrium credit price of \$4.98 at a 2:1 trading ratio (Maryland Department of the Environment 2017).¹⁰

At lower equilibrium credit prices, fewer farmers will find it profitable to switch from the conservation subsidy program into trading, and fewer unenrolled farmers will join trading. This will affect the average cost of nitrogen abatement in both the existing subsidy program and the trading program. First, consider the farmers who stay in the subsidy

program (Group 1, the Stayers). As the credit price decreases, a larger share of enrolled farmers continue collecting conservation subsidies, and adverse selection in the program is not worsened to the same extent. For example, if point-source upgrade costs are \$9.97 per pound (instead of \$15.80 per pound), average abatement costs among Stayers are only 1% higher compared to what they were prior to trading, when conservation subsidies were the only option. Among farmers who leave the conservation subsidy program to participate in trading (Group 2, the Switchers), lower credit prices imply that only the most efficient farms (with very high abatement per acre) are cannibalized by the trading program. However, many of these high-abatement farms are also estimated to exhibit high levels of nonadditional adoption, as they are more likely to adopt cover crops without subsidy payments. Thus, the average cost of nitrogen abatement among these farmers initially increases as the equilibrium credit price declines, for example rising to over \$20 per pound at point-source upgrade costs of \$9.97. Finally, among currently unenrolled farms that may find it profitable to join the trading program (Group 3, the Joiners), lower credit prices likewise imply that only the most efficient farms with high abatement are likely to trade. However, the estimated behavioral responses indicate that many of these high-abatement farms are more likely to have already adopted cover crops, and are also more likely to reduce their vegetative cover to maximize program payments. Thus, the average cost of actual nitrogen abatement obtained through trading can once again increase—for example, an estimated four-fold increase at a point-source upgrade cost of \$9.97—as farmer participation declines due to the low price of offset credits.

Now consider changes in the trading ratio from the 2:1 nonpoint/point-source trading ratio proposed in Maryland's water quality trading program rules. Water quality trading programs in other regions have proposed different trading ratios. At a 3:1 ratio, three units of nitrogen reduction are required by a nonpoint source to offset one unit at a point source, thus lowering the credit price farmers receive. Since higher trading ratios result in a lower equilibrium credit price for farmers,

¹⁰Another recent study using grants received by Maryland wastewater treatment plants from 2008 to 2011 estimated a sewage treatment plant willingness to pay of \$8.37 per pound of nitrogen in 2010 dollars, implying a maximum credit price of \$4.19 per pound at a 2:1 trading ratio (Dowd 2015). The results discussed in the sensitivity analysis are qualitatively the same at that lower price.

the results of a sensitivity analysis around a 3:1 trading ratio are analogous to those described above. For Group 1 (Stayers), higher trading ratios imply that fewer enrolled farmers switch into the trading program, and the adverse selection problem in the existing program is not substantially worsened. For Groups 2 and 3, higher trading ratios imply that only the most efficient farms (with high abatement per acre of cover crops) will likely switch into or join the trading program. As described above, these are the farms estimated to exhibit lower additionality and higher likelihood of lost vegetative cover in the behavioral model. Thus, average nitrogen abatement costs actually increase for these groups at a 3:1 trading ratio when considering farmer behavioral responses.

This sensitivity analysis indicates that the magnitude of our results may change in different regions or under different program design features. At the same time, the main conceptual results are similar regardless of the specific attributes that determine the threshold for sorting between conservation subsidy and trading programs. Introducing trading in a policy landscape with conservation subsidies will worsen adverse selection in the existing subsidy program, though the extent to which this problem occurs becomes smaller when fewer farms leave the subsidy program. Average abatement costs among farms that may find it profitable to trade (Groups 2 and 3) are substantially higher when considering the potential for nonadditional adoption and lost vegetative cover among these groups. These main results are important given the theoretical cost-effectiveness of trading when analyzed in isolation and without consideration of farmer behavioral responses.

The potential for adverse behavioral responses by voluntary trading participants implies a need for safeguards that should be included in any nonpoint/point-source trading contract. One possible mechanism in our case would be to create contracts stipulating that only farms with recorded cropping histories are eligible for either conservation subsidy payments or offset credit sales, in order to ensure that land previously in vegetative cover is not converted to cropland. Currently the cover crop and proposed water quality trading

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 or offset credit sale 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.

More generally, our results underscore the importance of careful design in implementing market-based policies. Specific features of the environment in which market-based policies operate have been shown to result in undesirable outcomes. Lack of care in the design of California's wholesale electricity markets rendered those markets vulnerable to unnecessary blackouts and price manipulation (Borenstein 2002). Lack of coordination among overlapping energy-sector programs has resulted in low additionality and a bias toward the dirtiest fossil fuels (Bohringer and Rosendahl 2010; Fischer and Preonas 2010; Tsao, Campbell, and Chen 2011). These experiences indicate that meeting water quality goals using market-based mechanisms will similarly require careful attention to market design to ensure sufficiently high additionality without inducing a loss of vegetative cover.

6. Conclusion

Water quality trading is 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 trading is that the incentives provided can be analyzed in isolation from existing agricultural conservation subsidy programs. Yet many trading programs will enter a policy landscape dominated by conservation subsidy programs, which will likely remain even as trading is introduced. This study investigates the likely interactions between these two types of programs in the context of Maryland's cover crop subsidy program and a proposed water quality trading program. We develop a conceptual framework

to elucidate how these two programs might interact. We then use an integrated assessment model constructed by combining econometric estimates of farm-level responses to cover crop payments with parameters from the Chesapeake Bay Program watershed model. This integrated assessment model allows us to see how the conservation subsidy and trading programs are likely to interact under various assumptions on program design.

Our analysis yields several main results and policy implications. First, our estimates indicate that the trading 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 conservation subsidy program; thus, analysis of the potential for trading to improve water quality, which ignores existing conservation subsidy programs, will tend to overstate new reductions in nitrogen emissions. Second, the introduction of trading worsens the adverse selection problem of conservation subsidy programs, as farmers with a comparative advantage in higher abatement levels per acre of cover crops are those farmers most likely to switch to selling offset credits. Third, because high-abatement farms leaving the conservation subsidy program do so in order to obtain higher payments in the trading program, introducing trading will increase total expenditures needed to achieve the same level of abatement previously obtained in the conservation subsidy program alone. Finally, the new nitrogen abatement from trading will depend largely on the response of high-abatement farmers not currently receiving conservation subsidies. We find that the total nitrogen abatement from this group joining the trading program could substantially increase the benefits obtained from the existing conservation subsidy program. However, the behavioral responses of farmers from this group—including nonadditional cover crop acreage and reduced vegetative cover—are estimated to be quite large, sometimes even perversely leading to increases in nutrient emissions. After accounting for these behavioral responses, the resulting average abatement costs among some farmers in this group may be higher than the cost of point-source upgrades, even when

trading ratios are incorporated to account for uncertainties associated with nonpoint-source reductions.

Our findings indicate the importance of understanding the interactions among policy instruments with different incentive structures, aimed at the same goal and available to the same groups of agents. Integrated assessment models represent an important tool for examining these types of interactions. Trading has the well-known potential for cost savings. Yet the actual environmental benefits accomplished by introducing a new trading policy will depend on how it interacts with existing subsidy programs. Carbon trading, for example, has been shown to operate at cross-purposes with other subsidy programs in the energy sector. Similarly, market-based programs for water quality improvements will achieve their potential only if their operating procedures are designed with a realistic understanding of how they might fit within the existing policy environment.

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