Emissions Trading Programs for Afforestation: Interactions with Federal Agricultural Conservation Programs

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Abstract: Emissions trading programs have been promoted as efficient means to reduce nonpoint source water pollution and sequester carbon from agricultural land. While trading programs are often evaluated in isolation, they compete with longstanding agricultural conservation subsidy programs. Both programs target agroforestry practices that provide environmental benefits using different payment structures: Trading pays for performance while agricultural conservation programs pay for effort. We evaluate the performance of both programs in isolation and competition using an integrated assessment model that combines a stated preference survey of agricultural landowners for establishing forests with biophysical models of water quality and carbon sequestration benefits of forests. Our numerical policy simulation suggests that the water quality trading program in isolation can provide sufficient financial incentives for landowners to engage in afforestation activities on agricultural land. However, federal agricultural conservation subsidies largely crowd out the trading program when in competition. Stacking payments for carbon offsets with water quality trading payments does not enhance trading participation. Overall, the attractiveness and effectiveness of emissions trading programs for afforestation activities on agricultural land are heavily influenced by the presence and level of federal agricultural conservation subsidies.

Keywords: emissions trading, carbon offset credit, agricultural conservation, agri-environmental programs, nature-based solutions
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1. Introduction

Emissions trading programs have been promoted as a flexible and cost-effective approach to incentivizing landowners to adopt farming practices that reduce runoff of fertilizers and pesticides, limit emissions of air pollutants, and sequester carbon (Weinberg and Claassen, 2006; Lankoski and Cattaneo, 2010; Shortle et al. 2012; Talberth et al. 2015). For instance, agricultural conservation practices are widely regarded as low-cost sources of supply for nutrient emission reduction credits in water quality trading markets (Fisher-Vanden and Olmstead, 2013; Stephenson and Shabman, 2017). Similarly, the Growing Climate Solutions Act of 2021 aimed to improve the access of agricultural landowners to carbon trading markets to supply carbon offset credits generated from agricultural conservation practices. Despite these efforts, landowner participation in both water and carbon trading programs has been low, an outcome generally attributed to such factors as high transaction costs, restrictive trading rules, and high ratios of nonpoint source emissions relative to point source emissions required to account for the fact that reductions in agricultural emissions vary from year to year (Fisher-Vanden and Olmstead, 2013; USDA, 2023).

We consider another reason for the failure of water quality trading to gain purchase: interactions with pre-existing agricultural conservation subsidy programs. The US, like other developed countries, has chosen a different approach to addressing nonpoint source pollution from agriculture, subsidizing farmers' use of environmentally beneficial farming practices. For example, agricultural conservation subsidy programs, authorized by quinquennial farm bills and administered by the U.S. Department of Agriculture (USDA), has been the primary source of payments addressing pollution problems emanating from agriculture (Lichtenberg, 2017). The 2002 farm bill initiated an increase in subsidies for conservation programs on working farmland and spending on those programs has risen with each subsequent farm bill (Stubbs, 2023). More recently, the Inflation Reduction Act of 2022 allocated an additional $19.5 billion to USDA conservation programs that subsidize the cost of adopting agricultural conservation practices. Trends in Europe have been similar: Agricultural subsidy programs within the European Union have shifted spending from traditional subsidies for crop production to agri-environmental schemes that pay farmers to adopt conservation practices, leading to fewer detrimental effects on environmental quality (Baylis et al. 2008).

Newly created emissions trading programs envisioning low cost sources of pollutant reduction from agriculture thus enter into a policy landscape where the federal agricultural conservation programs have been a primary source of funding for environmental services from agriculture (Fleming et al., 2020). The two types of programs pay on markedly different bases: Emissions trading programs pay on the basis of performance (reductions in emissions or increases in carbon sequestration) while agricultural subsidy programs pay on the basis of effort (use of specific farming practices). In the US, payments in programs promoting conservation on working farmland such as the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), and the Conservation Reserve Enhancement Program (CREP) are based on the direct and implicit costs of adopting conservation practices. In contrast, emissions trading, such as the water quality and carbon offset credit trading, pays on the basis of the modeled amount of nutrient runoff reduction or carbon sequestered by the installed conservation practice in the water quality or carbon trading programs. The two modes of payment compete: Farmland owners are generally prohibited from "double dipping", i.e., accepting payment from two different programs for the same set of actions.

We investigate how these two types of programs interact in the context of afforesting streambanks, a practice that provides a multitude of ecosystem services including water quality and carbon sequestration benefits. We conduct numerical policy simulations to evaluate the performance of the conservation subsidy and emissions trading programs operating both in isolation and in competition with each other. We develop an integrated assessment model that integrates two key components: (i) a spatially explicit stated preference model of landowner decisions about installing conservation cover parameterized using survey data on landowner and farm characteristics, and (ii) biophysical models estimating site-specific water quality and carbon sequestration benefits. We begin by analyzing baseline scenarios in which each program operates independently and thus serves as the sole financial incentive available to landowners for adopting conservation practices. We then extend our analysis to a policy scenario where both programs simultaneously offer payments for adopting the same conservation practice, with landowners permitted to enroll in only one program. Under these scenarios, we assess how differences in payment structure influence the characteristics of landowners attracted to each program and the resulting implications for three primary performance metrics: participation rates, environmental benefits, and total payments made to landowners.

Our policy simulation offers several important insights into the impacts of pre-existing conservation subsidy programs on the performance of water quality trading markets. First, we find that when agricultural conservation subsidy programs are absent, water quality trading program has the potential to encourage a significant number of landowners to adopt afforestation practices. Second, we find that, in our case at least, carbon payments are small and therefore provide limited incentives for establishing forest cover on agricultural land. Third, we find that conservation subsidies largely outcompete water quality trading at current payment levels: Participation in the conservation subsidy program remains largely the same as when the program operates in insolation while participation in water quality trading programs is much lower than when it operates in isolation. Finally, we find that stacking water quality payments with carbon sequestration payments has a minimal impact on increasing overall participation in emissions trading programs. Overall, these findings suggest that pay-for-effort subsidies provided by longstanding federal conservation programs are generous enough to largely crowd out pay-for-performance incentives from water quality trading markets in promoting afforestation practice on agricultural land. We obtain this conclusion under conditions that are relatively favorable for water quality trading, in that we assume that transaction costs and the effects of restrictive rules are the same for both water quality trading and agricultural conservation programs.

Our analysis also suggests that the introduction of emissions trading can reduce the cost-effectiveness of existing conservation subsidy programs, as landowners selectively switch to trading only when performance-based payments exceed effort-based incentives. This sorting behavior may lower net environmental benefits of the pre-existing subsidy program compared to a scenario in which it operates alone. More generally, competing financial incentives from overlapping policies affect overall conservation outcomes through two distinct channels: (i) by reallocating of land between programs without increasing total conservation acreage, reflecting land that would have enrolled in one program in isolation but instead shifts to the other under competition, and (ii) by expanding total conservation acreage, as additional landowners choose to enroll who would not have participated under either program alone. These two channels underscore the need for coordinated policy design to ensure that market-based and publicly funded conservation efforts complement rather than undermine each other.

Transaction volumes in water quality trading programs across the US have remained highly limited. Further, most trades have taken place between point sources, with the agricultural sector, long believed to be a low cost source, playing little or no role. Prior work has focused on obstacles to participation such as high transaction costs, restrictions on what kinds of trades can be made, and high nonpoint:point source trading ratios attributed (Ribaudo and Gottlieb 2011; Fisher-Vanden and Olmstead 2013; Liu and Brouwer 2023). Our analysis demonstrates that another factor is likely significant: Competition with federal agricultural conservation programs, which have expanded substantially in recent years in both scope and size of financial incentives (Shortle and Horan 2013; Savage and Ribaudo, 2016; Stubbs, 2023). More generally, our analysis thus adds to the growing literature showing that more is not always better in policy, i.e., that overlapping environmental policy instruments can reduce overall performance (Goulder and Parry 2008; Fischer and Preonas 2010; Fischer et al. 2017).

Agricultural conservation subsidy programs have been the main instrument used to address nonpoint source pollution from agriculture in developing countries and, as such, have played an important role in environmental policy overall. At the same time, these programs have been criticized for various kinds of inefficiencies. For example, they generally fail to target payments toward areas offering the highest environmental benefits (Reichelderfer and Boggess 1988, Babcock et al., 1997; Wu and Boggess, 1999) and are subject to imperfect additionality (Lichtenberg and Smith-Ramirez 2011; Mezzatesta et al., 2013; Claassen et al. 2018; Fleming et al 2018; Lichtenberg, 2021; Rosenberg and Pratt, 2024). Our analysis demonstrates another problem associated with reliance on agricultural conservation programs to address agricultural nonpoint emissions: At current payment levels, these programs crowd out emissions trading programs that are generally considered more cost-effective (Lankoski and Cattaneo, 2010; Shortle et al. 2012; Rabotyagov et al. 2014). A previous study by Fleming et al. (2020) showed that such crowding out could occur in the context of cover crops, a conservation practice that must be renewed annually. Our analysis examines the interactions between agricultural conservation programs and emissions trading in the case of long-term (10-15 year) conservation contracts where the crowding out effect is found to be much larger.

The remainder of this paper is organized as follows. Section 2 describes the construction of the numerical simulation model, which consists of a site-specific model of landowner responses to different attributes of conservation contracts combined with biophysical models used to quantify site-specific environmental benefits of afforestation. Section 3 outlines the simulation method and policy scenarios in the numerical policy analysis. Section 4 reports the results of the policy simulations and presents sensitivity analyses. Section 5 concludes with a discussion of key findings and policy implications.

2. Numerical Simulation Model

We study the interactions between water quality trading and pre-existing conservation subsidy programs such as CREP using a numerical simulation that consists of three components. The first is a random utility model of farmland owner's willingness to install a riparian buffer in return for receipt of funding from either a conservation program or water quality trading, parameterized using data from a stated preference survey. The second is a model of impacts of riparian buffer installation on nutrient and sediment runoff. The third is an ecosystem demography model of carbon sequestration. All three models are site-specific and linked via geospatial location.

2.1 Empirical Estimation of Program Participation

This section presents the empirical framework used to estimate the probability that a farmland owner enters into a contract to plant and maintain forest vegetation in surface water frontage currently used for crop production. Our empirical analysis is based on the random utility model and a discrete choice experiment (DCE), developed and analyzed in Lichtenberg et al. (2025). Section 2.1.1 summarizes the survey design, sampling strategy, and descriptive statistics, while Section 2.1.2 introduces the random utility framework that relates the participation decisions of heterogeneous farmland owners to program design features. We leverage variation in program attributes in the DCE to study how participation varies across contract structures. These participation probabilities, when combined with spatially defined program-eligible acreages, yield expected enrollment and environmental outcomes at the parcel level. These expected outcomes serve as key inputs into our integrated simulation framework comparing conservation subsidies and emissions trading programs.

2.1.1 Stated Preference Data

We empirically analyze landowner's decision to participate in a conservation contract that converts cropland located in environmentally sensitive area into conservation cover using data from a stated preference survey developed and conducted by Lichtenberg et al. (2025) in collaboration with regional experts and administrators of agricultural conservation programs. The address-based survey of agricultural landowners in the Chesapeake Bay region aimed to understand key program attributes and characteristics of landowner and parcel that influence landowner's decision to establish conservation cover in riparian buffer areas of the Chesapeake Bay watershed.

The survey began with questions on landowner and farm operation characteristics that can influence the adoption of conservation practices, such as parcel rental status, share of household income from farming, landowner's risk preference and attitudes towards property monitoring and farm support programs, and prior experience with riparian buffers and farm support programs (Prokopy et al., 2019). Subsequently, DCE questions were presented to landowners who indicated in the survey that they either do not have conservation cover in the riparian buffer zone or only have partial coverage, which represents the target group for potential expansion of afforestation activities in agriculture. The DCE asked landowners who lacked conservation cover in riparian zones near environmentally sensitive waterways to make binary choices of establishing forest or grass cover under varying offered program attributes such as payment levels and contract lengths.

Figure 1 provides an illustrative example of one of four DCE questions assigned to the landowner. The DCE questions were constructed following best practices recommended by Johnston et al. (2017). To enhance consequentiality, the DCE used a two-alternative choice format where landowners selected between a proposed program and a status quo option (i.e., no program enrollment) rather than a three-alternative format (Johnston et al., 2017; Weng et al., 2021). Each landowner faced four distinct choice scenarios, each requiring a binary response regarding their enrollment in a proposed program to establish conservation cover within the riparian buffer zone of property for a specified period. The DCE varied program attributes commonly found in existing agricultural conservation contracts: vegetation type of the conservation cover, a one-time upfront payment, delays in upfront payment timing, a fixed recurring annual payment, and contract duration. The choice scenarios were constructed using a D-efficiency criterion that minimizes the standard errors of the estimated parameters in a logit specification (Scarpa and Rose 2008). Landowners were explicitly instructed to treat each DCE question as an independent and non-additive decision.

Table 1 lists program attributes with their possible levels in the DCE. The range of these attributes was calibrated to align with the existing agricultural conservation subsidy program for riparian buffer conservation by the federal-state partnership, specifically the CREP that incentivizes the establishment of conservation cover on agricultural lands adjacent to streams and rivers in the Chesapeake Bay. To better capture the preferences of landowners not currently adopting afforestation practices, the range of program payments was set higher than those currently offered by CREP, while ensuring the payment levels remained plausible and incentive-compatible (Vossler et al., 2023). In addition, the survey clarified that installation and maintenance costs for conservation covers would be fully covered, reflecting the prevailing level of funding for riparian buffers provided by conservation subsidy programs.

The survey sampling targeted Maryland agricultural parcels either intersecting or adjacent to surface water bodies, such as streams, rivers, and wetlands, by overlaying spatially explicit polygon data from the Maryland tax assessor database with the United States Geological Survey (USGS) National Hydrography Dataset. The sample was further refined to parcels exceeding 10 acres allocated to major agricultural uses, such as grain crops, hay, pasture, fruits, and vegetables, based on the 2020 USDA Cropland Data Layer. In cases where landowners held multiple parcels, one parcel was randomly chosen for survey participation, resulting in a sample of 8,923 parcels that are located in the Chesapeake Bay watershed and potentially eligible for payments to establish conservation cover in the riparia buffer area under federal agricultural conservation and emissions trading programs, aimed at enhancing water quality and carbon sequestration.

Invitations to participate in an online survey, with an option to request a paper copy of the survey, were then mailed to landowners between May and July 2021, each including a unique identification number to link their responses to the geospatial characteristics of their parcels (e.g., proxy for annual crop return and site-specific environmental benefits). A total of 1530 landowner responses were received, resulting in a response rate of 17%. Among the survey participants, 540 landowners answered at least one DCE question, leading to a total of 2,119 binary choices for establishing conservation cover in the riparian area under a set of randomly assigned program attributes. Our policy simulation focuses on these 540 landowners who either lacked conservation cover on their riparian buffer zones or had established riparian buffers on only a portion of their stream frontage. This focus aligns with ongoing policy discussions regarding the use of both market-based and subsidy-based financial incentives to encourage the adoption of conservation practices in agriculture beyond current levels.

Panel A and B of Table 2 provides descriptive statistics on landowners' enrollment decisions and their demographic and operational characteristics within the sample participating in the DCE. On average, landowners were offered a one-time payment of $835 per acre upfront, in addition to a fixed annual payment of $414 per acre over a contract period ranging from 5 to 15 years.

Landowners expressed their willingness to establish either grass or forest cover on their riparian areas in 35% of the proposed programs. This relatively high rate of program enrollment is consistent with the fact that the average annual payments offered exceeded the estimated site-specific annual crop returns from the riparian buffer areas.

Roughly half of the landowners were owner-operators, with the other half renting out a portion of their farmland to tenants. Farm income made up a relatively small portion of their overall household income. Approximately one-quarter of respondents were risk-averse and had prior experience with riparian buffer adoption without compensation, as well as participation in farm support programs. In addition, more than half of the landowners were seniors and expressed opposition to the government's property monitoring activities. In the following subsection, we introduce our empirical framework to analyze how these program attributes and landowner and farm characteristics influence enrollment decisions.

2.1.2 Random Utility Model of Farmland Owner Participation Decisions

We analyze program participation decisions independently relative to the status quo. Each landowner i faces a riparian buffer program j with different set of program attributes. Suppose that the landowner i with characteristics X_i participates in the program j that requires installation of the riparian buffer in program j for T_j years. Let θ_j be an indicator of the type of riparian buffer vegetation specified in program j, which equals 1 for forest and 0 for grass. Participation obligates the landowner to install riparian buffers at a cost of c_{ij}. In addition, the landowner receives (i) a cost-share payment that covers s_j portion of installation cost upfront, (ii) a one-time signing bonus payment k_j with d_j years of delay in payment timing, and (iii) a fixed recurring annual payment r_{ij} during the contract period T_j. Note that the signing bonus and cost-share rate vary according to program type (forest versus grass) only. In contrast, the recurring annual payment, which is based on soil productivity, varies across cropland parcels.

The expected indirect utility from participating in program j for landowner i is:

$$V_{ij} = \beta_0\left[k_{ij} - (1 - s_j)c_{ij}\right] + \sum_{d_j>0} \beta_{d_j}\mathbb{1}\{D_j = d_j\}k_j + \left(\gamma_{T^0} + \sum_{\tau_j<T^0} \gamma_{\tau_j}\mathbb{1}\{T_j = \tau_j\}\right)r_{ij} \quad (1)$$

$$+\kappa\theta_j + X_i\zeta + \alpha + \varepsilon_{ij},$$

where the baseline contract length is T^0 ($\tau_j < T^0$). The constant term α represents status quo utility common to all landowners and ε_{ij} is a set of unobservable factors that affect landowner i's decision to enroll in the program j.

The coefficient β_0 represents the landowner's utility from the upfront payment net of adoption cost under program j. The coefficient β_{d_j} represents how d_j years of delay in the timing of program payment affects landowner's program participation incentives. The coefficient γ_{T^0} represents the landowner's utility from the annual payment r_{ij} provided by the program j for T^0 years. The coefficient γ_{τ_j} captures potential variability in the value of the annual payment stream with contract length T_j. The term $\alpha + X_i\zeta$ represents the farmland owner's status quo utility, which varies across landowners of with different characteristics captured by the vector X_i such as age, education, risk preference, prior experience with the conservation practice, attitudes towards farm support programs along with parcel-specific characteristics, such as property size, the share of farm income, and annual crop returns associated with the riparian buffer area.

We assume that the error term ε_{ij} follows an i.i.d. type 1 extreme value distribution and thus estimate the parameters of equation (1) using logit. In our numerical policy simulation, predicted participation probabilities calculated from this logit model serves as the basis for simulating landowner program participation decisions across programs. Our simulations use additionality-adjusted estimated probabilities of participation in a program of type j adjusted as defined by:

$$\tilde{\hat{P}}_{ij} \equiv \hat{P}_{ij} - \hat{P}_{i0} = \frac{\exp(\hat{V}_{ij})}{1 + \exp(\hat{V}_{ij})} - \frac{\exp(\hat{V}_{i0})}{1 + \exp(\hat{V}_{i0})}. \quad (2)$$

where $\hat{V}_{i0}$ denotes the probability that farmland owner i participates in a program with vegetative cover of type j in the absence of any external payments (i.e., $r_{ij} = k_j = s_j = 0$). We make this adjustment to net out riparian vegetative planting by landowners whose private net benefits outweigh private costs and who are thus likely to self-fund buffer installation.

Table 3 presents the estimated parameters of the logit model. Overall, our findings are consistent with those in Lichtenberg et al. (2025) and Prokopy et al. (2019). Briefly, we find that financial incentives, such as payment type, payment level, and the cost of conservation are important drivers of participation in the riparian buffer contracts. Both higher upfront and annual payments significantly increase the likelihood of enrollment. In contrast, the opportunity cost of land, proxied by the foregone annual crop return, decreases the likelihood of participation. The estimated parameters of the model indicate that neither delays in receipt of the upfront payment nor differences in contract length have any statistically discernible effect on the likelihood of program participation. Finally, the estimated parameters of the logit model indicate a number of sources of heterogeneity in the likelihood of participation, notably prior experience with riparian buffers, risk aversion, tenure status, share of household income from farming, landowner age, and attitudes toward government farm programs.

2.2 Environmental Benefits of Program Participation

Establishing riparian buffers on agricultural land provides a multitude of ecosystem services, such as reducing nutrient runoff, sequestering carbon, enhancing wildlife habitat and aquatic ecosystems, and mitigating stream bank erosion (Belt et al., 2014; Sweeney and Newbold, 2014). This section explains the methodology used to calculate the site-specific amount of nutrient load reductions and carbon sequestration by riparian forest buffers. We use these estimates for two purposes. First, we monetize the parcel-specific environmental benefits using the social cost of nutrient loads to the Chesapeake Bay and the social cost of temporary carbon offsets from the U.S. EPA. Second, we calculate the amount of emission offset credits generated from each parcel, which is then converted to payments offered by the emissions trading programs.

2.2.1 Water Quality Benefits

To calculate water quality benefits of riparian forest buffers, we estimate the time profile of N and P runoff reduced by riparian buffers using spatially-varying parameters from the Chesapeake Bay Watershed Model (CBWM) (Belt et al., 2014; CBP 2022; Kim et al., 2024). The CBWM has been used by the EPA and Bay states to evaluate the impact of conservation practices on nutrient reductions to meet Chesapeake Bay total maximum daily loads (TMDL), which is a regulatory framework established by the EPA to limit specific pollutants that water bodies can receive while still meeting water quality standards. The CBWM allows for modeling and assessment of these impacts at a localized geographical scope. For instance, the model parameters include pollutant loads by land use across counties, nutrient runoff removal rate of riparian buffers across hydrogeomorphic regions, and delivery ratio of pollutant load from the nearest edge of the stream to the Bay across land-river segments that are smaller than the sub-watershed level (USGS's 12-digit Hydrologic Unit Code). These spatially explicit data on water quality benefits of riparian buffers are then overlaid with each parcel's 35-ft width riparian buffer area identified using high resolution (1-meter) land use and land cover data developed by the Chesapeake Conservancy, USGS, and the University of Vermont Spatial Analysis Lab (CBPO, 2022). Recent studies have also used these parameters to evaluate the environmental benefits and cost-effectiveness of conservation programs under various policy scenarios (Talberth et al., 2015; Fleming et al., 2018; Fleming et al., 2020).

The establishment of riparian forest buffers on cropland has both direct and indirect water quality improvements. Direct benefits stem from the immediate reduction in pollutant loads as cropland, which generally has higher fertilizer use and soil erosion, is converted to forest buffers. These direct reductions in pollutants persist throughout the contract period and vary depending on the specific county and land-river segment where the buffers are established. Indirect benefits include the decreased pollutant loads as the established riparian buffers filter nutrient and sediment runoff from adjacent cropland before they reach nearby streams and rivers. These benefits grow over time as the buffer matures and removes greater amount of pollutant loads (Hairston-Strang, 2005; Simpson and Weammert, 2009; Belt et al., 2014).

Let b_{it}^{z} denote the expected annual reduction in pounds of pollutant z achieved per acre of forest established on parcel i. For water quality benefits, we consider $z \in \{N, P\}$, which comprises both direct and indirect pollutant load reductions and can be expressed as:

$$b_{it}^{z} = \underbrace{\left(d_{i,\,\text{crop}}^{z}\alpha_{i,\text{crop}}^{z} - d_{i,\,\text{forest}}^{z}\alpha_{i,\text{forest}}^{z}\right)}_{\text{direct reduction}} + \underbrace{\alpha_{i,\text{crop}}^{z}x^{z}\psi_{it}^{z}d_{i,\text{crop}}^{z}}_{\text{indirect reduction}}, \quad \text{where } z \in \{N, P\}. \tag{3}$$

The first bracket is the direct reduction of pollutant load, estimated by the difference in pollutant loads between forest cover and cropland. The parameters $\alpha_{i,\text{crop}}^{z}$ and $\alpha_{i,\text{forest}}^{z}$ are the per-acre loads of pollutant z from cropland and forest cover measured at the edge of the nearest stream for parcel i. The parameter $d_{i,\text{crop}}^{z}$ and $d_{i,\,\text{forest}}^{z}$ are delivery ratio factors to account for attenuation occurring while the pollutant loads are transported from the landowner's cropland and riparian forest buffers, respectively, to the Chesapeake Bay.

The second term is the indirect reduction of pollutant load, that is, the amount of pollutant load from adjacent cropland treated by an acre of installed riparian forest buffers, which equals the product of four parameters: (i) pollutant loads from an acre of cropland on parcel i, $\alpha_{i,\text{crop}}^{z}$, (ii) the ratio of neighboring cropland acres to buffer acres for which the efficiency rate applies, x^{z}, (iii) the proportion of pollutant loads removed by an acre of t-year-old forest buffer on parcel i, ψ_{it}^{z}, known as the efficiency rate, and (iv) the delivery ratio of pollutant from crop field to the Bay, $d_{i,\text{crop}}^{z}$.

We monetize the amount of direct and indirect reductions in N and P loads into the social benefits. Let m^{z} denote the fixed social cost of emitting per pound of pollutant z during the contract period, which is set as follows for nitrogen and phosphorus: $m^{N} = \$17.11$ and $m^{P} = \$207.63$ in 2021 value (Choi et al., 2020). Thus, the present value of expected water quality benefits per acre of riparian forest buffers established in each parcel i under program j during the contract period T_j is:

$$B_{ij}^{\text{water}} \equiv \sum_{t=0}^{T_j-1} \delta^{t} \left(\sum_{z=\{N,P\}} b_{it}^{z} m^{z} \right). \tag{4}$$

The calculated average water quality benefits are \$11,688/acre (in 2021 USD) when converting cropland in the riparian buffer area into forest cover for 15 years.

2.2.2 Carbon Sequestration Benefits

To calculate carbon sequestration benefits, we use high-resolution raster data on the trajectory of carbon storage growth for newly established forest cover on bare ground generated by Ecosystem Demography Model (Ma et al., 2021; 2022a; 2022b). The model incorporates spatial and temporal variation in weather conditions (temperature, precipitation, etc.), soil characteristics (depth, water retention, etc.), and atmospheric CO_2 concentrations to estimate forest aboveground biomass. Thus, the model provides localized estimates of carbon storage densities of forest in kilograms of carbon per square meter for each 30m by 30m grid cell, covering most of the northeastern United States.

This carbon raster data set is overlaid with agricultural land within 35-feet riparian buffer area of all surveyed parcels within the Chesapeake Bay region. We then construct the time profile of the amount of carbon sequestered by riparian forest buffers newly established on each parcel. We first calculate the arithmetic mean of the carbon storage densities in each grid cell for the riparian buffer area. We then repeat the same process for each year in the raster data, yielding year-specific trajectory of aboveground biomass (AGB) storage density estimates for each parcel. To account for changes in belowground biomass (BGB) over time, we include an additional 20% of the aboveground biomass, based on the ratio of BGB to AGB derived from the USDA Forest Service's National Forest Inventory data (1990-2022) (Hoover and Smith, 2021; Domke et al., 2023).

We monetize the amount of carbon stored by established forests, using the social value of offsets (SVO) framework proposed by Groom and Venmans (2023). Unlike the social cost of carbon (SCC), which quantifies the economic damages from permanently emitting an additional ton of CO_2, the SVO recognizes the value of temporary storage of carbon through short-term conservation projects. This distinction is crucial, as carbon stored through these projects may be re-released once contracts expire.

The SVO framework makes several primary adjustments to the SCC valued in the beginning of the conservation period. First, it accounts for variations in the timing of carbon sequestration throughout the contract duration. Specifically, this adjustment captures the delayed onset of sequestration by applying a present value discount for the time lag between the current period and the time of annual carbon sequestration throughout the contract period. Second, the framework also incorporates the growth rate of the SCC to reflect changes in the SCC during both the sequestration and release periods. Third, the framework addresses the impermanence of carbon storage, recognizing that sequestered carbon may be released back into the atmosphere upon the conclusion of the conservation contract. Finally, the SVO accounts for the risk of non-additionality and project failure, which could diminish the overall carbon sequestration benefits of conservation projects. Overall, these adjustments account for the duration of carbon storage, impermanence, and failure risk associated with carbon sequestration benefits under short-term conservation projects.

In our simulation, we assume: (i) perfect additionality of funded conservation projects, (ii) minimal risk of non-compliance or project failure during the contract term, and (iii) limited growth in the SCC during the contract period. These assumptions likely result in an upper-bound estimate of carbon sequestration benefits, given that conservation cover under payment for ecosystem services (PES) programs often exhibits imperfect additionality (Mason and Plantinga 2013; Mezzatesta et al. 2013; Claassen et al 2018; Lichtenberg 2021), is subject to non-compliance (Cattaneo 2003; Kim et al. 2024; Pathak et al. 2024), and the SCC tends to increase over time (Nordhaus, 2017). Conversely, our estimates may undervalue carbon sequestration benefits by assuming that all carbon stored through these projects will be re-released upon contract expiration, even though some established forests may persist beyond the contract period (Bigelow et al. 2020). Our findings are robust to changes in these assumptions as the carbon sequestration benefit and corresponding payments are negligible compared to the benefits and payments from water quality improvement.

The present value of carbon sequestration benefits of establishing forest cover on cropland in parcel i for T_j years is:

$$B_{ij}^{\text{carbon}} = \sum_{t=0}^{T_j-1} b_{it}^{C} m^{C}, \tag{5}$$

where b_{it}^{C} is the expected metric tons of carbon sequestered by the newly established forest cover on parcel i in each period t, and m^{C} is the SVO of carbon sequestered from time t to the contract expiration date T_j. We obtain m^{C} from the product of (i) estimated SCC from Carleton and Greenstone (2022) and the EPA (2023), \$120/metric ton CO_2 which is equivalent to \$460.72 per metric ton of carbon in 2021 values adjusted by SVO formula. On average, the annual amount of carbon sequestered by the newly established riparian forest buffers is 0.42 metric ton of carbon per acre during the 15-year contract.

3. Policy Simulation Method

We describe the simulation method used to evaluate the performance of conservation subsidy and emissions trading programs both in isolation and with potential interactions between them. In the former scenario, each program is evaluated separately as the sole financial incentive for landowners to adopt conservation practices on their agricultural land. In the latter scenario, landowners can voluntarily enroll in one type of program to receive payments for adopting conservation practices, but they are not permitted to enroll in both simultaneously. We leverage estimated landowner responses to program attributes and landowner characteristics obtained from the stated preference study. Using these estimated parameters, we simulate landowner's enrollment probabilities under each program. We then use an integrated assessment model to link individual landowner program enrollment probabilities with environmental benefits. Simulated program performance metrics include the expected conservation acreage established and participation rate of each program, environmental benefits, and payments made to the landowners in return.

3.1 Program Type

Our simulation focuses on a 15-year contract for establishing forest cover on cropland located within 35-feet width of the riparian area. The stated preference study indicates two statistically significant factors influencing landowner enrollment decisions: payment type and level. Thus, we focus on the difference in one-time upfront payment and recurring annual payments offered by these programs, holding other program attributes the same.

Table 4 summarizes the payment types and payment levels offered by the federal conservation subsidy program, water quality trading, and carbon trading. The payment structure varies considerably across the three programs. The water quality trading program offers relatively high annual payments that are linked to site-specific reductions in nutrient runoff, while the conservation subsidy program offers lower annual payments based on parcel-specific soil rental rates. However, unlike emissions trading programs, conservation subsidy program provides an upfront payment that helps cover the initial costs of establishing riparian forest buffers. The carbon trading program offers payments based on carbon offset credits, but the financial incentive is relatively weak at the current market rates for carbon offsets. This distinction in payment structure shapes the relative attractiveness of each program to landowners.

We also observe significant variability in payments from both conservation subsidy and emissions trading programs (Table 4). However, the sources of payment variability differ. In conservation subsidy program, variability arises from differences in the opportunity cost of land use, as soil rental rates depend on the agricultural productivity of the parcel. In emissions trading programs, payment variability stems from differences in environmental benefits, as payments are linked to site-specific reductions in nutrient runoff or carbon sequestration potential. In the following subsections, we explain the methods used to calculate each program payment in detail.

3.1.1 Agricultural Conservation Subsidy Program

The agricultural conservation subsidy program in our simulation is modeled after CREP, a federal-state partnership established in 1997 aimed at reducing nutrient runoff from farmland and enhancing downstream water quality through agricultural conservation practices. CREP is the primary funding source for establishing conservation cover in the riparian area of farmland in the Chesapeake Bay watershed. The program typically offers a 15-year contract for riparian forest buffers featuring a cost-share payment that fully covers installation expenses, a signing bonus, and annual rental payments based on soil productivity (rather than environmental performance or pollution abatement outcomes).

We consider a scenario where CREP does not provide a one-time signing bonus payment but fully covers the cost of establishing forest on riparian area of agricultural land. Thus, we have:

$$s_{\text{subsidy}} = 1 \text{ and } k_{\text{subsidy}} = 0. \tag{6}$$

Because parcel-specific cost of establishing riparian forest buffers c_i is not available, we use the average installation cost in Maryland from the literature, which equals $2,212.63/acre (in 2021 USD) (Price et al., 2021).

We follow the USDA Farm Service Agency's general procedure to calculate CREP's annual conservation subsidy for riparian forest buffers $r_{i,\text{subsidy}}$, which typically proxies for the site-specific opportunity cost of land, ν_i, based on the annual rental rate of cropland and soil productivity of the land. In addition, the annual subsidy level is often adjusted by the program incentive rate $\iota \geq 1$ to further enhance conservation incentives:

$$r_{i,\text{subsidy}} = \nu_i \iota. \tag{7}$$

We set the annual payment per acre of riparian forest buffers equal to the site-specific soil rental rate multiplied by the incentive rate ι of 3. The parcel-specific soil rental rate is determined by the county-level soil rental rates for non-irrigated cropland from the USDA's NASS, adjusted for parcel-specific soil productivity in the 35-feet width of riparian buffer area as measured by the National Commodity Crop Productivity Index from the USDA's Natural Resources Conservation Service (NRCS). Our survey respondents were selected from a unique address-based sample, allowing us to estimate parcel-specific soil rental rates based on the distinct soil types present in each parcel's riparian buffer area. This detailed spatial information in modeling conservation subsidy incentives and environmental benefits allows for a more precise evaluation of the program's performance. On average, the annual payment offered for establishing riparian forest buffers is $207 per acre, with a standard deviation of $90 per acre (Table 4).

3.1.2 Water Quality Trading Program

In contrast to the conservation subsidy program, the emissions trading program offers financial compensation based on environmental services resulting from land-use conversion from cropland to forest. Examples include water quality trading programs in the major Chesapeake Bay watershed states (e.g., Maryland, Virginia, and Pennsylvania). Agricultural operations generate nutrient offset credits by implementing agricultural conservation practices that reduce N and P runoff, such as cover crops and riparian buffers, and then sell these credits to wastewater treatment plants or other entities that can offset their N and P load reductions required for compliance with regulatory requirements (Ribaudo and Shortle, 2019). The offset credits obtained from nonpoint source such as agricultural sector are subject to uncertainty in achieving water quality benefits and thus discounted when they are traded to offset pollutant loads from point source (Malik et al. 1993; Lankoski and Cattaneo 2010; Fisher-Vanden and Olmstead 2013).

Unlike conservation subsidy programs, water quality trading programs generally do not provide an upfront payment to subsidize the cost of adopting conservation practices. Thus, we set:

$$s_{\mathrm{WQT}} = 0 \text{ and } k_{\mathrm{WQT}} = 0. \tag{8}$$

Let $r_{i,\mathrm{WQT}}$ denote the annual payment from the water quality trading program for establishing riparian forest buffers on parcel i. Consistent with the annual payments shown in the stated preference survey, we construct a fixed schedule of constant annual payments based on the average reduction in N and P loads during the contract period. Specifically, let b_{it}^{z} denote the annual pollutant load reduction per acre of riparian forest buffers on parcel i at time t. Then, we calculate the contract period average of b_{it}^{z} that is $\bar{b}_{i}^{z} \equiv \frac{1}{T}\sum_{t=0}^{T-1} b_{it}^{z}$. This reduction is then multiplied by (i) the per-pound price of N and P load offsets in the water quality trading programs (p^N and p^P), and (ii) the trading ratio between nonpoint and point source pollutant loads, ϕ:

$$r_{i,\mathrm{WQT}} = \phi \sum_{z=N,P} \bar{b}_{i}^{z} p^{z}\,. \tag{9}$$

Since water quality trading programs in the Chesapeake Bay region do not publish transaction prices for N and P load credits, we assume landowners receive payments equivalent to the abatement costs for wastewater treatment plants by upgrading their facilities: \$20 per pound of N and \$106 per pound of P ($p^N = \$20$ per N and $p^P = 106$) (Jones et al. 2010). For the trading ratio between nonpoint source (agriculture) and point source (wastewater treatment plants) nutrient reductions in the trading market, we use 2:1 ($\phi = 0.5$) based on Maryland's trading and offset policy guidelines (MDE 2017). The resulting average annual payment from the water quality trading program is \$491/acre on average across 540 parcels with a standard deviation of \$184/acre (Table 4).

3.1.3 Carbon Trading Program

Establishing forest cover on agricultural land sequesters carbon, allowing landowners to earn carbon offset credits and sell them to the power sector under emissions reduction regulations. In our simulation, carbon trading payment is modeled after the Regional Greenhouse Gas Initiative (RGGI), which is a market-based cap-and-trading program in the northeastern United States to cap and reduce greenhouse gas emissions from the power sector. The participating states in RGGI include Maryland, Delaware, Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont (Virginia ceased its participation in 2023) Under RGGI, participating states issue a fixed number of allowances, each representing the right to emit one ton of CO_2. Power plants covered by RGGI must hold allowances to cover their emissions, either through allocation from the state or through purchasing allowances at auction. While the RGGI market primarily focuses on regulating emissions from power plants, it allows for the inclusion of offset projects from other sectors, such as agriculture, to achieve overall emission reduction goals.

We assume that landowners receive payments based on the expected increase in carbon storage when converting cropland to forest cover, with baseline carbon storage for cropland set to zero. Carbon trading programs generally do not provide one-time upfront payments to subsidize the installation costs of agricultural conservation practices. Thus, we set:

$$s_{\text{carbon}} = 0 \text{ and } k_{\text{carbon}} = 0. \tag{10}$$

Similar to the water quality trading program, we construct a fixed schedule of constant annual payment $r_{i,\text{carbon}}$, which equals the site-specific yearly average of carbon sequestered by the newly established forest cover on parcel i during the contract period $\bar{b}_i^C$ multiplied by the price of carbon offset credit per metric ton of carbon p^C:

$$r_{i,\text{carbon}} = \bar{b}_i^C p^C. \tag{11}$$

We obtain p^C from the average price of offset credits in RGGI's 2021 auctions, which is \$38/metric ton of carbon. The resulting annual payment from the carbon trading program is \$16/acre on average across 540 parcels with a standard deviation of \$5/acre (Table 4).

3.2 Policy Simulation Outcomes

To evaluate program performance, we first predict each landowner's enrollment probability under varying upfront and annual payments offered by the conservation subsidy and emissions trading programs. We then calculate the extent to which eligible crop acreage on each landowner's parcel is expected to be enrolled under each program. Finally, we link the expected conservation acreage with payments and environmental benefits to calculate three program performance metrics both under isolation and competition scenarios: program participation rate, environmental benefits, and program payments.

3.2.1 Landowner's Probability of Program Participation

We begin with the scenario where program j is the only source of payments offered to landowner i for adopting riparian forest buffers. In this case, the estimated probability that landowner i enrolls in program j is $\tilde{\hat{P}}_{ij}$ as specified in equation (2).

Next, we consider a case where landowners face two competing programs, j and l, each offering different sets of payments, (r_{ij}, s_j, k_j) and (r_{il}, s_l, k_l) for the adoption of riparian forest buffers. Landowners are not allowed to enroll in both programs and must choose one program to enroll in. We assume that each farmland owner chooses the program with higher utility or, equivalently, higher enrollment probability. For instance, the landowner i prefers emissions trading program if the expected utility from trading-based payments exceeds that from the subsidy:

$$V_{i,\text{trading}}(r_{i,\text{trading}}, s_{\text{trading}}, k_{\text{trading}}) > V_{i,\text{subsidy}}(r_{i,\text{subsidy}}, s_{\text{subsidy}}, k_{\text{subsidy}}). \tag{12}$$

Given the program attributes in our policy simulation, the sorting condition above simplifies to:

$$\sum_{t=0}^{T-1}\left(\sum_{z}\bar{b}_i^z p^z\right)\delta^t > s_{\text{subsidy}}c_i + \sum_{t=0}^{T-1}\nu_i\iota\delta^t\,. \tag{13}$$

If the inequalities are reversed, the landowner is assumed to enroll in the conservation subsidy program. Implicit in this sorting criterion are the assumptions that (a) P_{i0} and (b) unobserved landowner-specific participation costs ε_{1i} are the same for all programs (and thus it does not alter the landowner's choice between programs). This latter assumption is likely favorable to the emissions trading program, since transaction costs are typically higher for water quality trading than for government conservation programs.

This sorting condition implies that the emissions trading program is more attractive to landowners with specific characteristics. For instance, landowners with high pollution reduction potential, such as those located on land with high baseline emissions or in proximity to sensitive ecosystems, are more likely to benefit from the pay-for-performance structure. For these landowners, the quantity $\bar{b}_i^z$ is large, increasing the expected revenue from trading pollutant reduction. In addition, landowners with low conservation costs c_i or agricultural productivity, which determines the annual subsidy payment $r_{i,\text{subsidy}}$, relative to environmental benefits, may also prefer emissions trading.

3.2.2 Program Performance Metrics

Using the program-induced probability obtained for isolation and competition scenarios, we calculate the expected acreage conserved under each program, accounting for both the scale of eligible land and the responsiveness of individual landowners to financial incentives. Let A_i denote the acreage eligible for conservation on landowner i's property. Then, the expected acreage conserved under program j is:

$$\text{Conservation Acreage}_j \equiv \sum_{i \in I_j} A_i \tilde{\hat{P}}_{ij} \,. \tag{14}$$

In the isolation scenario, all eligible landowners evaluate program j independently of any alternatives, so I_j includes the entire eligible population. In the competition scenario, landowners choose between two mutually exclusive programs (e.g., j and l), and I_j becomes the subset of landowners for whom program j offers higher utility ($I_j = \{i \mid \tilde{\hat{P}}_{il} < \tilde{\hat{P}}_j\}$). Thus, competition affects the set of participating landowners as well as the location and environmental characteristics of enrolled land.

The change in acreage conserved by each program under the competition scenario can be explained by two channels: substitution and expansion. The substitution effect captures the reallocation of conservation acreage between the two programs rather than a net increase in conservation outcomes. It reflects land that would have been enrolled under one program in isolation but instead shifts to the other program when both are offered simultaneously. The expansion effect captures the net increase in conservation acreage attributable to the availability of additional program. It represents land that would not have been enrolled under either program operating alone but is enrolled under the competition scenario. The substitution and expansion effects together decompose the total conservation acreage achieved under competition.

This decomposition provides important insights into the overall environmental outcome in the presence of two competing incentive-based programs for conservation. If program competition results predominantly in substitution, the primary effect is a transfer of funding responsibility rather than an expansion of conservation outcomes. In such cases, total program payments may rise as landowners sort into the program offering higher payment, but the environmental benefits remain largely unchanged. In contrast, if program competition results in the enrollment of additional acreage that would not have been conserved under either program operating alone, the overlapping policy efforts yield a net increase in the provision of environmental services. The relative magnitude of each effect depends on the heterogeneity of landowner opportunity costs, environmental attributes, and the extent to which the competing programs differentiate in their payment structures. Overall, the composition of participating landowners, and thus the location and quality of enrolled land in each program, can shift substantially due to program competition despite little change in the total conservation acreage conservation.

The participation rate for program j measures the proportion of total eligible acreage enrolled:

$$\text{Participation Rate}_j \equiv \frac{\sum_{i \in I_j} A_i \tilde{\tilde{P}}_{ij}}{\sum_i A_i}. \tag{15}$$

Participation may increase under competition if the presence of an alternative program makes enrollment financially viable for additional landowners. Changes in participation reflect both the sorting of landowners across programs (substitution) and the induced participation of previously non-participating landowners (expansion).

Assuming that environmental benefits are additively separable across pollutant types z and proportional to the conservation acreage, the present value of expected environmental benefits from program j over a contract duration of T years is:

$$\text{Environmental Benefits}_j \equiv \sum_{i \in I_j} A_i \tilde{\tilde{P}}_{ij} \sum_{t=0}^{T-1} \delta^t \left(\sum_z b_{it}^z m^z \right). \tag{16}$$

This measure captures spatial heterogeneity in ecosystem service provision, which may vary across landowners due to topography, soil characteristics, and proximity to waterways or pollutant sources.

The total environmental benefit under program competition may exceed that achieved under either program operating in isolation when the introduction of a second program induces additional participation through the expansion effect. This expansion is likely when the conservation subsidy fails to compensate many landowners for the opportunity cost of conservation. In contrast, an emissions trading program, linked to a pollution offset price, can offer stronger financial incentives for parcels with high environmental benefits that were undervalued by the subsidy scheme due to high costs. In such cases, the emissions trading program complements the pre-existing subsidy program by facilitating the conservation of environmentally valuable land that would otherwise remain in production.

Conversely, the total environmental benefits will remain unchanged relative to the single program scenario if the substitution effect dominates. Instead, the substitution effect can substantially alter the composition and spatial distribution of environmental benefits across programs without a net expansion in conservation acreage. For instance, the emissions trading program, structured as pay-for-performance, is more likely to conserve land with higher pollution abatement potential. The conservation subsidy program would be more likely to conserve land where the offered subsidy is higher than the actual cost of conservation. Both programs result in non-random selection into programs in terms of environmental attributes and agricultural productivity of land.

Total program payments represent the present value of all financial transfers made to landowners participating in conservation contracts over the contract duration of T years. For program j, total payments are given by:

$$\text{Program Payments}_j \equiv \sum_{i \in I_j} \left[s_j c_i + \sum_{t=0}^{T-1} \delta^t r_{ij} \right] A_i \tilde{\hat{P}}_{ij}. \tag{17}$$

Compared to the isolation scenario, changes in total program payments under the competition are driven by substitution and expansion effects. The expansion effect increases total payments by enrolling landowners who would not have participated under a single-program setting. The substitution effect, on the other hand, increases total payments to landowners even without expanding the overall enrolled acreage and environmental services, as landowners switch to the program offering higher compensation for the same conservation action.

Overall, the comparison of program performance metrics across isolation and competition scenarios highlights the trade-offs inherent in the design of overlapping conservation payment schemes. Expanding the policy menu to include both subsidy and trading programs can enhance environmental performance by increasing total enrolled acreage. However, these benefits may come at the cost of increased program expenditures with little increase in the environmental benefits, driven by landowner sorting behavior and the redistribution of conservation acreage and payments across programs. This underscores the importance of coordinating multiple incentive-based conservation instruments.

4. Policy Simulation Results

This section presents the performance of three conservation incentive programs under the following three scenarios. The first scenario examines each program as a stand-alone payment option for landowners. The second scenario explores the competitive interaction between the federal conservation subsidy program and the water quality trading program. The third scenario considers whether combining payments for carbon sequestration with water quality trading payments enhances landowner participation and program performance. We also explore how fluctuations in pollution offset prices affect the performance and interaction of the conservation subsidy and emissions trading programs. Finally, we investigate the type of landowners attracted to each program, focusing on the opportunity costs of land use and environmental benefits.

To assess the robustness of program performance estimates, we calculate the confidence intervals for policy simulation outcomes, employing the Krinsky and Robb (1986) method. This method has been widely used in existing studies to account for the uncertainty in estimated model parameters and generate a distribution of possible land use outcomes (Lewis 2010; Lewis et al. 2011). The procedure begins by constructing a multivariate normal distribution of parameter estimates from the logit model in equation (1), using the parameter estimates presented in Table 3 along with the corresponding covariance matrix. Next, we draw a vector of model parameters from this distribution. For each draw, we recalculate the probability of enrollment for each parcel and use these probabilities to compute program participation rate, environmental benefits, and program payments made to landowners. By repeating this process over 1,000 draws, we obtain an empirical distribution of each program outcome. We then use the 2.5th and 97.5th percentiles of this empirical distribution to construct 95 percent confidence intervals.

4.1 Program Performance in Isolation

We first compare the performance of the federal agricultural conservation subsidy program and the two emissions trading programs when each program is offered as a stand-alone option for landowners (Panel A in Table 5). The results reveal that the conservation subsidy program achieves much higher participation rates and environmental benefits compared to the other two programs.

The participation rate under the conservation subsidy program (11.4%) is approximately twice that of the water quality trading program (5.7%), even though the annual payment from the water quality trading program ($491/acre) is roughly 2.5 times higher than that of the conservation subsidy program ($207/acre). This finding can be attributed to landowners' strong preference for upfront payments from the conservation subsidy program, as revealed in the stated preference study (Table 3), which shows a high marginal rate of substitution between upfront and annual payments.

The carbon trading program exhibits the lowest participation rate (0.2%) among the three conservation incentive programs. This outcome is expected given the relatively low market price for carbon offsets, which fails to provide sufficient financial incentives for landowners to engage in afforestation activities on agricultural land. Unlike federal conservation subsidy programs, which offer upfront payments to cover establishment costs, emissions trading programs solely rely on recurring annual payments. This payment structure may deter landowner participation in contexts where early-stage financial support is important to establish natural infrastructure.

The total environmental benefits obtained increase with the program's participation rate. The conservation subsidy program delivers the highest environmental benefits, followed by the water quality trading program, while the carbon trading program provides only marginal benefits. The conservation subsidy program's upfront payment is cost-effective at enhancing program participation compared to the annual payments offered by emissions trading programs. As a result, the conservation subsidy program achieves 122% higher net environmental benefit and a benefit-payment ratio of 2.5, compared to 1.9 for the water quality trading program (Panel A of Table 5). In contrast, the carbon trading program attracts minimal landowner participation at current market rates, leading to negligible environmental benefits. These findings suggest that the current market rate for carbon offset credit provides limited incentives for farmers to engage in afforestation activities on agricultural land when used as a stand-alone incentive scheme.

4.2 Program Performance in Competition

Suppose that both the conservation subsidy program and the water quality trading program offer competing incentives for afforestation, but landowners can only participate in one program (Panel B of Table 5). The results indicate that participation in the conservation subsidy program remains stable whereas participation in the water quality trading program drops sharply from 5.7% to

0.06%. These findings highlight the importance of upfront payments and subsidizing the initial costs of afforestation. While pay-for-performance programs link payments directly to the expected annual flow of environmental benefits, the immediate financial support provided by pay-for-effort incentives attracts landowners, crowding out participation in the trading program.

Competition between the two programs does not lead to higher environmental benefits net of program payments either. Compared to the isolation scenario (Panel A of Table 5), total environmental benefits from the conservation subsidy program and the water quality trading program decline by 1% and 98.3%, respectively. Similarly, environmental benefits net of payments decrease by 1.3% and 98.3%, as landowners sort into the program offering the highest payments. These results suggest that introducing the emissions trading into a policy landscape where conservation subsidies are the dominant funding source may reallocate landowner participation at higher payments rather than expand overall conservation efforts, which undermines overall environmental outcomes.

Consider a scenario in which carbon offset payments are “stacked” with payments for water quality improvements to increase landowner participation in the emissions trading program (Panel C of Table 5). The results indicate little to no improvement in overall program performance. Participation in the emissions trading program remains low, while the conservation subsidy program continues to attract the majority of enrollees. Carbon offsets fail to provide sufficient financial incentives to induce additional participation. Given the relatively small size of carbon payments compared to water quality or conservation subsidies, these findings suggest that carbon offset credit alone, even at elevated price levels, are unlikely to serve as an effective mechanism for incentivizing afforestation in agriculture.

These results are obtained based on several assumptions that are favorable to emissions trading programs. For instance, pollution offset credit programs typically require a portion of credits to be withheld as buffer credits. Specifically, a percentage of credits is allocated to a buffer pool or reserve account to insure against reversal risks, such as wildfire or non-compliance. In addition, we abstract away from transaction costs associated with program enrollment by assuming that these costs are equivalent across the conservation subsidy and emissions trading programs. This assumption is likely favorable to the emissions trading as it often requires third-party verification of environmental outcomes and imposes additional costs or risks on participants relative to conservation subsidy programs. Thus, the simulation results may overstate the relative attractiveness of emissions trading programs in environments where transaction costs are large.

Finally, different payment structures in the two programs attract distinct types of landowners (Panel A of Table 7). The pay-for-effort subsidies in the conservation subsidy program are designed to offset landowners' foregone crop returns, whereas the pay-for-performance structure of emissions trading payments rewards landowners based on pollution reductions. Consequently, landowners in the emissions trading program generate, on average, 73% higher annual environmental benefits than those in the conservation subsidy program. However, the crop returns of emissions trading participants are comparable to those of conservation subsidy participants. This divergence highlights the influence of payment structures on the types of landowners who engage in afforestation under conservation contracts.

4.3 Sensitivity Analysis

This section examines how changes in market prices for pollution reduction influence the performance of conservation subsidy and emissions trading programs (Table 6). Since N reduction accounts for the largest share of payments in the emissions trading program, the analysis focuses on a scenario where N prices increase by 50% relative to the baseline. This price increase also reflects a policy scenario in which a 50% discount on pollution reductions from nonpoint sources, such as agricultural runoff, is removed in the water quality trading market. While the analysis centers on nitrogen, similar effects are expected for increases in the prices of P and C reductions.

The results can be explained by the two primary channels of program interaction discussed earlier. The substitution effect emerges as a higher N price enhances the attractiveness of pay-for-performance schemes in emissions trading relative to the conservation subsidy program. Higher payments offered by the emissions trading program incentivize landowners to shift from the conservation subsidy program to emissions trading. As a result, participation in the conservation subsidy program declines from 11.2% to 9.1%, while participation in the emissions trading program rises from 0.2% to 3.0% (Panels C of Tables 5 and 6). Accordingly, environmental benefits obtained from emissions trading also increase substantially, while those from the conservation subsidy program diminish, reflecting substitution effect.

This reallocation also changes the composition of participants in the two programs. Landowners who enroll in the emissions trading program under higher N prices achieve 50%

greater environmental benefits but incur 7% lower crop returns compared to participants in the conservation subsidy program (Panel B of Table 7). The difference in environmental benefits between participants in the two programs is also statistically significant. However, this reallocation reduces the environmental benefits achieved through the conservation subsidy program, lowering its benefit-payment ratio from 2.43 to 2.15 (Panels C of Tables 5 and 6). This decline highlights how emissions trading programs can draw high-performing participants away from subsidy programs, reducing their cost-effectiveness in providing environmental benefits.

The second channel, the expansion effect, arises as higher pollution offset prices incentivize new landowner participation or expand the conservation acreage of participating landowners. Under baseline conditions, some landowners may find participation in either program financially unviable. However, the increase in financial incentives offered by the emissions trading program encourages previously uninvolved landowners to engage in afforestation activities. As a result, total program participation rises from 11.4% to 12.0% and total environmental benefits by 8.2% compared to the baseline scenario (the expansion effect) (Panels C of Tables 5 and 6). This finding suggests that higher pollution offset prices also lower financial barriers to entry, leading to an overall increase in conservation practice adoption in addition to reallocating participants between programs.

Overall, these findings demonstrate the dual effects of competing incentives introduced by emissions trading programs. On the one hand, pollution offset credits can expand participation by attracting new landowners who may not have engaged in conservation efforts under baseline conditions. This expansion effect increases overall adoption of conservation practices, contributing to broader environmental benefits. On the other hand, emissions trading programs reduce the cost-effectiveness of pre-existing subsidy programs by attracting high-performing participants toward market-based schemes. This reallocation alters the benefit-payment ratio of the conservation subsidy program, making it more sensitive to changes in emissions trading market conditions, an interaction that does not arise when the subsidy program operates in isolation. Thus, the evaluation of emissions trading programs should consider these interactions with pre-existing subsidy programs.

5. Conclusion

This study examined the interaction between emissions trading programs and federal agricultural conservation programs in promoting afforestation on agricultural land. Our findings reveal that, when evaluated in isolation, water quality trading programs have the potential to offer substantial financial incentives and greater environmental benefits net of program payments compared to traditional conservation subsidy programs. However, their effectiveness and participation rates largely depend on the presence and generosity of pre-existing federal conservation subsidies. Moreover, supplementing water quality payments with carbon payments does little to enhance the attractiveness of emissions trading programs for afforestation, primarily because the current market rates for carbon offsets are too low. In addition, competition between these programs does not necessarily enhance the cost-effectiveness of conservation efforts, as landowners tend to sort into the program offering the highest financial compensation rather than expanding total participation in afforestation. As a result, the cost-effectiveness of pre-existing conservation subsidy program is influenced by fluctuations in pollution offset prices.

From a policy perspective, these results underscore the challenges of relying solely on emissions trading to drive afforestation in agricultural landscapes. Sensitivity analyses demonstrate that emissions trading programs become more competitive when pollution offset prices rise or when adoption costs decrease, yet the lack of upfront payments remains a significant barrier to participation. Thus, emissions trading programs would be most viable when targeting low-cost conservation practices or offering partial upfront payments that blend features of both subsidy- and market-based approaches. Otherwise, high-cost conservation practices that require substantial upfront investment will continue to favor pay-for-effort subsidies.

Our evaluation of program performance has several limitations and caveats. First, the numerical simulation adopts assumptions that favor emissions trading with respect to landowner participation. Specifically, we assume that offset programs do not withhold a portion of credits for buffer pools to insure against risks such as reversals and leakage. We also assume equal transaction costs across programs, even though emissions trading may involve higher costs due to the verification of environmental benefits. We also exclude one-time signing bonuses offered by some conservation subsidy programs. Together, these assumptions are likely favorable to emissions trading programs. Second, we abstract from broader social welfare considerations beyond environmental outcomes and landowner payments, likely understating the overall social benefits of emissions trading by omitting potential efficiency gains from trade between regulated entities and landowners. Similarly, we do not account for the distributional impacts of shifting financial responsibility from taxpayers (under a beneficiary-pays conservation subsidy) to regulated industries (under a polluter-pays emissions trading scheme), a shift that may carry implications for equity and political feasibility.

Despite these limitations, our analysis effectively serves the research objective of comparing the relative performance of conservation subsidy and emissions trading programs in promoting conservation practices. By holding the set of potential conservation actions constant and allowing competition only through payment structure differences, we provide a tractable and transparent comparison. This approach isolates and compares: (i) how payment structure influences landowner participation decisions; (ii) which types of landowners and land enroll under each program individually and in competition; and (iii) how much land is newly conserved versus switching between programs. This focused analysis offers valuable insights for program design and coordination in policy landscapes where agricultural conservation subsidies and environmental markets increasingly coexist and interact.

Despite growing policy interest in the supply of carbon offset credits through agricultural conservation practices (González-Ramírez et al., 2012; Thompson et al., 2022; van Kooten and Zanello, 2023; Raina et al., 2024), agriculture accounted for less than three percent of carbon credits issued between 2013 and 2022 (USDA, 2023). Several barriers prevent farmers from participating in the carbon markets, including risk and uncertainty in carbon prices, policy uncertainty related to climate change mitigation policies, and the complexity of the market (Dumbrell et al., 2016; Kragt et al., 2017; USDA, 2023). In particular, transaction costs associated with adopting conservation practices in return for payment have been extensively examined to promote the adoption of agricultural conservation practices (Peterson et al., 2015; Palm-Forster et al., 2016; Banerjee et al., 2017; Johnston et al., 2023). However, our results suggest that even if these impediments are removed, competition with existing pay-for-effort programs would likely be a significant barrier to emissions trading. Ongoing discussion on the implementation of emissions trading as a mechanism for promoting afforestation should account for its interaction with pre-existing subsidy programs, as the structure and generosity of conservation subsidies significantly shape landowner decisions and program effectiveness.

List of Tables and Figures

Table 1. Descriptions of Program Attributes in a Discrete Choice Experiment

Program Attribute	Description
Vegetation type	Vegetation type of the riparian buffers: forest or grass
Upfront payment	One-time upfront bonus payment for program enrollment: $200, $500, $1,000, or $1,500 per acre
Annual payment	Recurring annual payments for a specified contract period: $100, $250, $500, or $750 per acre
Delays in upfront payment	Delays in the timing of upfront payment: 0, 2, or 5 years
Contract length	Number of years to maintain the established riparian buffers: 5, 10, or 15 years

Table 2. Description of Variables from the Survey and Summary Statistics

Variable	Description	Mean	SD
Panel A. Discrete choice experiment (2,119 choice observations)			
Enroll	A binary indicator for enrollment in a proposed program	0.35	0.48
Upfront payment	One-time upfront payment ($/acre)	835	484
Annual payment	Annual payment ($/acre)	414	249
Panel B. Landowner and farm characteristics (540 parcels)			
Crop Return	Calculated foregone annual crop income ($1,000/acre)	0.30	0.14
Rent Out	A binary indicator for renting out any land within a parcel	0.81	0.39
Farm Income	Share of household income from farming	0.15	0.27
Farm Support	A binary indicator for participation in any farm support programs: crop/revenue insurance, livestock insurance, Farm Service Agency loans, dairy margin coverage or margin protection program, price support programs (commodity loans, loan deficiency payments, etc.)	0.23	0.42
Subsidy	A binary indicator for any payments received for existing forest/grass cover in the riparian area	0.06	0.24
Self-funder	A binary indicator for having any self-funded forest/grass cover in the riparian area	0.26	0.44
Senior	A binary indicator for age over 65	0.56	0.50
College	A binary indicator for having a college degree or higher	0.61	0.49
Risk Averse	A binary indicator for being risk averse	0.27	0.45
Oppose to Property Monitoring	A binary indicator for agreement on the following statement: the government should not be allowed to come onto my property and monitor my farmland operations	0.61	0.49
Oppose to Farm Support	A binary indicator for agreement on the following statement: tax revenues should not be used for farm support programs	0.19	0.39
Crop Area	Cropland within a 35ft-width riparian buffer zone (acre)	2.28	2.25
Property Size	Property size (acre)	88.60	73.53

Notes: The discrete choice experiment includes a total of 2,119 choice observations from 540 parcels with characteristics or landowner and parcels. Foregone annual crop return is approximated using national commodity crop productivity index and cash rental rate for non-irrigated cropland following Kim et al. (2024).

Table 3. Estimated Parameters of the Logit Model

Variable	Outcome: Enroll = 1	
Panel A. Program attributes	Coef.	S.E.
Upfront payment (baseline: no delay)	0.27*	(0.13)
Upfront payment × 2-year delay	-0.11	(0.13)
Upfront payment × 5-year delay	-0.12	(0.12)
Annual payment (baseline: 15-year contract)	0.81***	(0.25)
Annual payment × 5-year contract	-0.10	(0.26)
Annual payment × 10-year contract	0.22	(0.24)
Forest cover (baseline: Grass cover)	-0.12	(0.10)
Panel B. Landowner and parcel characteristics		
Crop Return	-1.09**	(0.36)
Rent Out	0.32*	(0.14)
Farm Income	-0.39	(0.22)
Farm Support	-0.33*	(0.14)
Subsidy	0.66**	(0.21)
Self-Funder	0.41***	(0.11)
Senior	-0.71***	(0.10)
College	0.15	(0.11)
Risk Averse	-0.79***	(0.12)
No Prop Monitor	-0.64***	(0.10)
No Tax Support	-0.30*	(0.13)
Constant	0.05	(0.24)
Number of observations: 2,119 choice observations from 540 parcels		

Notes: In addition to the variables shown above, the estimation includes binary indicators for parcels with missing characteristics.

p-value $^{*} < 0.05$, $^{**} < 0.01$, $^{***} < 0.001$

Table 4. Summary Statistics of Program Payments in Policy Simulation

Description	Parameter	Mean	SD
One-time upfront payment ($/acre)	s_{subsidy}	2,213	0
	s_{WQT}	0	0
	s_{carbon}	0	0
Annual payment ($/acre/year)	$r_{i,\text{subsidy}}$	207	90
	$r_{i,\text{WQT}}$	491	184
	$r_{i,\text{carbon}}$	16	5

Notes: For all programs, we consider a 15-year contract that establishes riparian forest buffers with no delays in upfront payment. All monetary values are measured in 2021 USD.

Table 5. Policy Simulation Results: Baseline

Program	Participation Rate	Total Benefits ($ in 1,000s)	Total Payments ($ in 1,000s)	Net benefits ($ in 1,000s)
Panel A. Programs in isolation				
Conservation Subsidy	11.4% [4.8%, 15.7%]	1,691 [716, 2312]	685 [302, 933]	1,006 [418, 1379]
WQT	5.7% [2.5%, 9.1%]	954 [422, 1528]	501 [222, 804]	452 [200, 725]
Carbon Trading	0.2% [0.08%, 0.26%]	24 [11, 37]	0 [0, 1]	23 [11, 37]
Panel B. Programs in competition: Subsidy v. Water Quality Trading				
Conservation Subsidy	11.4% [0.9%, 15.7%]	1,675 [77, 2307]	682 [63, 932]	993 [10, 1378]
WQT	0.06% [0.0%, 6.8%]	16 [0, 1220]	9 [0, 644]	8 [0, 577]
Total	11.4% [7.0%, 15.7%]	1,691 [1086, 2312]	690 [507, 959]	1,001 [529, 1378]
Panel C. Programs in competition: Subsidy v. Water Quality Trading + Carbon Trading				
Conservation Subsidy	11.2% [0.8%, 15.7%]	1,637 [62, 2307]	674 [57, 932]	963 [8, 1378]
WQT + Carbon	0.21% [0.0%, 7.2%]	55 [0, 1289]	30 [0, 698]	25 [0, 591]
Total	11.4% [7.0%, 15.7%]	1,692 [1099, 2312]	703 [513, 974]	989 [527, 1378]

Notes: This table presents the results of policy simulations under three distinct scenarios. Scenario in Panel A evaluates the performance of the agricultural conservation subsidy program, the water quality trading (WQT) program, and the carbon trading program, each as the sole source of payment for landowners to adopt conservation practices. Scenario in Panel B allows landowners to choose payments from either the WQT or subsidy programs, but not both simultaneously. Scenario in Panel C examines the impact of combining payments for both carbon sequestration benefits and water quality improvements within the trading program. The parametric bootstrap with 1000 iterations (Krinsky and Robb, 1986) is used to construct the 95 percent confidence intervals of the policy simulation results, as shown in parentheses.

Table 6. Policy Simulation Results: Increases in Prices for Nitrogen Offset Credit

Program	Participation Rate	Total Benefits ($ in 1,000s)	Total Payments ($ in 1,000s)	Net benefits ($ in 1,000s)
Panel A. Programs in isolation				
Conservation Subsidy	11.4% [5.5%, 15.4%]	1,691 [793, 2222]	685 [332, 912]	1,006 [464, 1312]
WQT	8.7% [3.4%, 14.1%]	1,479 [557, 2333]	1,144 [430, 1804]	336 [127, 529]
Carbon Trading	0.2% [0.07%, 0.26%]	24 [10, 37]	0 [0, 1]	23 [10, 36]
Panel B. Programs in competition: Subsidy v. Water Quality Trading				
Conservation Subsidy	9.3% [0.7%, 15.0%]	1,224 [40, 2145]	565 [48, 883]	659 [-4, 1248]
WQT	2.71% [0.0%, 12.6%]	597 [0, 2160]	471 [0, 1672]	127 [0, 485]
Total	12.0% [8.5%, 16.1%]	1,821 [1261, 2447]	1,036 [624, 1835]	785 [368, 1270]
Panel C. Programs in competition: Subsidy v. Water Quality Trading + Carbon Trading				
Conservation Subsidy	9.1% [0.6%, 15.0%]	1,188 [31, 2138]	553 [40, 882]	635 [-7, 1246]
WQT + Carbon	3.0% [0.0%, 13.0%]	643 [0, 2220]	513 [0, 1754]	129 [0, 469]
Total	12.0% [8.6%, 16.3%]	1,831 [1264, 2497]	1,066 [626, 1906]	764 [352, 1266]

Notes: This table presents results of policy simulations when nitrogen offset credit is 50% higher than the baseline value. The simulation considers the same three distinct scenarios as the baseline simulation. Scenario in Panel A evaluates the performance of the agricultural conservation subsidy program, the water quality trading (WQT) program, and the carbon trading program, each as the sole source of payment for landowners to adopt conservation practices. Scenario in Panel B allows landowners to choose payments from either the WQT or subsidy programs, but not both simultaneously. Scenario in Panel C examines the impact of combining payments for both carbon sequestration benefits and water quality improvements within the trading program. The parametric bootstrap with 1000 iterations (Krinsky and Robb, 1986) is used to construct the 95 percent confidence intervals of the policy simulation results, as shown in parentheses.

Table 7. Landowner Characteristics by Program

Program	Crop Return ($/acre/year)	Environmental Benefits ($/acre/year)	Landowner Share
Panel A. Programs in competition: baseline			
Conservation Subsidy	298 (143)	1108 (316)	99.81
Emissions Trading	295 (155)	1920 (129)	0.19
Diff in Mean: p-value	0.96	<0.001	
Panel B. Programs in competition: 50% higher pollution offset credit prices			
Conservation Subsidy	302 (149)	1012 (262)	81.2
Emissions Trading	281 (119)	1519 (228)	18.8
Diff in Mean: p-value	0.17	<0.001	

Notes: This table presents the average values of annual crop return and environmental benefits for parcels enrolled in either conservation subsidy or emissions trading programs (that offer water quality plus carbon trading payments) under a scenario of competition. Standard deviation is presented in parenthesis.

Would You Enroll?

Assume that **Program A** was offered as a possible program. Would you enroll in this program to install and maintain a riparian buffer on your property? If you choose "yes", we will ask you the length of the buffer (in feet) you would install under the chosen program.

Please remember that:

- Installation costs and maintenance costs will be fully covered by the program, regardless of the buffer type offered in the program
- You will receive the one-time bonus payment **at the time you enroll in the program**
- The program requires a minimum buffer width of 35 feet

Program element	**Program A**
Buffer type	Forest buffer
Bonus payment ($/acre)	$500
Annual payments ($/acre)	$250
Contract length (years)	15

The payment schedule for **Program A** will look like the following:

	Program A
Year 0 – Bonus payment ($/acre)	$500
Year 1 – Annual payment ($/acre)	$250
Year 2 – Annual payment ($/acre)	$250
Year 3 – Annual payment ($/acre)	$250
Year 4 – Annual payment ($/acre)	$250
Year 5 – Annual payment ($/acre)	$250
Year 6 – Annual payment ($/acre)	$250
Year 7 – Annual payment ($/acre)	$250
Year 8 – Annual payment ($/acre)	$250
Year 9 – Annual payment ($/acre)	$250
Year 10 – Annual payment ($/acre)	$250
	Contract ends

Would you enroll in **Program A**? (Choose one)

- ○ Yes – I would enroll
- ○ No – I would not enroll

Figure 1. An Illustrative Example of a Discrete Choice Experiment Question

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