Adoption of Agricultural Conservation Practices: Experimental Insights for Policy Design

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This research is supported by the Hughes Center for Agro-Ecology & Maryland Agricultural Experimental Station

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Payment for Ecosystem Service (PES) Programs

- **Adoption of long-term conservation practices**
  - Substantial funds in USDA programs for long-term practices on working lands (e.g., riparian buffers, filter strips)
    - Conservation Reserve Enhancement Program (CREP) & continuous signup Conservation Reserve Program (CRP)
  - PES programs provide upfront and recurring annual payments for a specified contract period
    - Long-term practices needed because environmental benefits depend on vegetation growth that takes time to mature
- **Voluntary nature of landowner enrollment**
  - Need for experimental approach to analyze the effectiveness of program design features on landowner behavior (Messer et al. 2024)

Economic Incentives for Riparian Buffers

- **Conservation Reserve Enhancement Program (CREP)**
  - Federal-state partnership started in 1997
  - Long-term contracts (10-15 years) for grass and forest buffers
    - Full installation costs
    - Signing bonus
    - Annual payments based on soil rental rate and buffer maintenance

- **Maryland's Conservation Buffer Initiative**
  - Maryland Department of Agriculture initiated pilot program in 2021
  - Shorter contracts (5-10 years)
  - Higher upfront payment (in lieu of annual payments)

Research Questions

- How effective are upfront payments relative to annual payments in incentivizing participation in farm conservation programs?

- How effective are shorter contract lengths in incentivizing participation?

Objectives and Approach

- **Goal**: Evaluate landowner participation, environmental benefits, and program costs under different policy scenarios

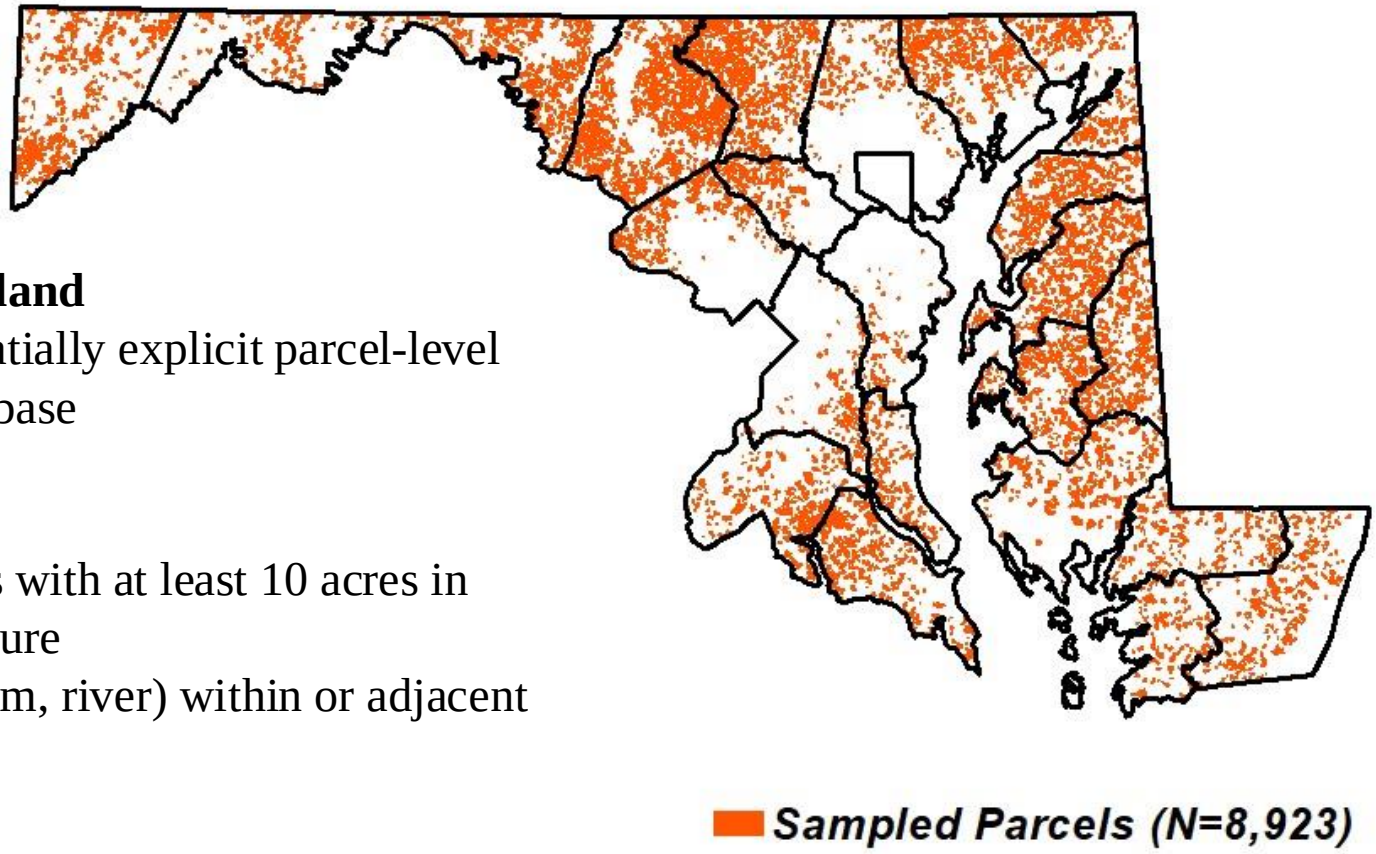
- **Policy scenarios**
  - CREP (baseline)
  - Maryland's Conservation Buffer Initiative
    - Upfront vs. annual payments
    - Shorter contracts
  - Targeting bonus payments based on environmental benefits
  - CREP plus carbon offset payments

- **Econometric model**: Estimate farm-level probability of enrollment for installing riparian buffers using landowner survey
    - Discrete choice experiment on buffer program attributes (upfront bonus payments, annual payments, contract length, buffer vegetation type)
    - Models: Logit & Two-stage hurdle models

- **Integrated assessment model**: Site-specific environmental benefits for landowner enrollment for forest and grass buffers
    - Water quality (N and P reductions in Chesapeake Bay)
    - Carbon sequestration (forest buffers)

Part I:
Landowner survey &
Choice experiment for modeling alternative buffer incentive programs

Buffer Survey for Agricultural Landowners



All counties in Maryland

- Sample using spatially explicit parcel-level tax assessor database

Screening criteria

- Farmland parcels with at least 10 acres in crops or hay/pasture
- Waterbody (stream, river) within or adjacent to parcel

Survey implementation

- Mailed letter to participate in online survey via Qualtrics
- Unique ID linked to landowner parcel
- Full sample 8,923 landowners with 1,530 survey respondents (17% response rate)

Buffer Survey Data

- Riparian buffer history
  - Buffer acreage, year installed, cost-share received (yes/no), buffer type
- Farm-level management
  - Crop type acreages, % rented, farm income
- Landowner demographics and attitudes
  - Age, education, % income from farming
  - Attitudes toward farm support programs, government monitoring farm practices, taking on long-term risky investments
- Spatial site-specific parcel data in GIS
  - Land cover and area in riparian zone
  - USDA soil rental rate (SRR) based on dominant soil types
  - National Commodity Crop Productivity Index (NCCPI)

Discrete Choice Experiment: Proposed Buffer Program Attributes

Program attribute	What it means
Buffer type	**Type of buffer to be installed**. Options include: Grass buffer, forest buffer
Bonus payment	**One-time upfront bonus payment for program enrollment.** Options include: $200, $500, $1,000, $1,500 per acre
Annual payments	**Recurring annual payments**. Options include: $100, $250, $500, $750 per acre
Contract length	**Number of years to maintain the buffer**. Options include: 5, 10, 15 years
Payment delay	**Number of years delay in upfront bonus payment is received.** Options include: 0, 2, 5 years

- Assume minimum buffer width of 35 feet per program requirement
- Installation and maintenance costs are fully covered

Example: Proposed Buffer Program

- 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 X**
Buffer type	Grass buffer
Bonus payment ($/acre)	$500
Annual payments ($/acre)	$250
Contract length (years)	10

The payment schedule for **Program X** will look like the following "Example" table:

	Program X
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 X**? (Choose one)

○ Yes – I would enroll

○ No – I would not enroll

Each landowner answers 4 randomly assigned program designs

Landowner and farm/parcel characteristics

Variable	Description	Mean	S.D.
Soil rental rate	Parcel-specific soil rental rate ($1,000/acre)	0.08	0.03
Farm income	Share of household income from farming	0.16	0.27
Binary Indicator Variables (Yes=1; No =0)			
Senior	Age over 65	0.56	0.50
Rent	Rents out some or all farmland within the parcel	0.50	0.50
College	Has a college degree or higher	0.62	0.49
Risk averse	Is risk averse	0.29	0.45
Enrollee	Received payments for buffers already existing on parcel	0.06	0.24
Self-funder	Landowner self-funded buffers already existing on parcel	0.27	0.44
Opposition to property monitoring	Agrees with statement: “The government should not be allowed to come onto my property and monitor my farmland operations”	0.60	0.49
Opposition to tax-funded farm programs	Agrees with statement: “Tax revenues should not be used for farm support programs”	0.19	0.39
N= 552 landowner parcels			

Econometric (Logit) Model on Program Enrollment

Expected indirect utility for landowner *i* from enrolling in program *j*, relative to status quo (no enrollment)

$$EV_{ij} = \alpha_i + \boldsymbol{X_i}\lambda + \delta z_{ij} + \beta_0 s_{ij} + \beta_2(s_{ij} \times D_2) + \beta_5(s_{ij} \times D_5)$$

$$+ \gamma_5 p_{ij} + \gamma_{10}(p_{ij} \times C_{10}) + \gamma_{15}(p_{ij} \times C_{15}) + \epsilon_{ij}$$

- α_i: constant term denoting status quo utility
- X_i: vector of landowner and farm/parcel characteristics
- z_{ij}: = 1 if forest buffer (baseline = grass buffer)
- s_{ij}: one-time signing bonus payment
- D_2, D_5: = 1 if 2 and 5 years of delay in receiving the one-time signing bonus (baseline = no delay)
- p_{ij}: annual recurring payments
- C_{10}, C_{15}: = 1 if a 10-year and 15-year contract (baseline = 5-year contract)

Logit Model Results

	Coefficient	S.E.
Program attribute variables		
Forest (baseline: grass buffer)	-0.13	0.10
Bonus payment (baseline: no delay)	0.26**	0.13
Bonus payment × 2-year delay	-0.10	0.13
Bonus payment × 5-year delay	-0.06	0.13
Annual payment (baseline: 5-year contract)	0.75***	0.27
Annual payment × 10-year contract	0.32	0.26
Annual payment × 15-year contract	0.14	0.26
Landowner and parcel characteristics		
Soil rental rate	-3.47***	1.68
% income from farming	-0.69***	0.20
Senior (yes=1)	-0.67***	0.10
Rent (yes=1)	0.26**	0.10
College degree (yes=1)	0.13	0.11
Risk averse (yes=1)	-0.77***	0.12
Current program enrollee (yes=1)	0.76***	0.21
Current self-funder (yes=1)	0.76***	0.11
No government monitoring (yes=1)	-0.67***	0.10
No farm support programs (yes=1)	-0.29**	0.13
Constant	-0.14	0.23

Number of choice-experiment observations: 2,021 (N= 552 landowners)

p-value: *** p<0.01, ** p<0.05, * p<0.1

Two-Stage Hurdle Models

- **Serial nonparticipation**
  - von Haefen, Massey, and Adamowicz (2005)
    - Single-hurdle model & Double-hurdle model
  - Our study
    - 46% of landowners chose not to enroll in any of the 4 randomly assigned proposed programs, despite payments offered higher than current CREP levels

- **First-stage: Probability of not participating in any program offered**
  - Probit model used to estimate probability that landowner rejects all 4 randomly assigned programs (i.e., chooses no enrollment for all 4 programs)
    - Identifies landowners with reservation prices outside the range offered in the survey (i.e., serial nonparticipants)

- **Second-stage: Probability of enrollment, conditional on participation**
  - Logit model used to estimate probability of enrollment in buffer program as a function of program attributes and landowner and farm/parcel characteristics (Enroll=1, Not enroll=0)

Hurdle Model Results: First-Stage
Probability of serial nonparticipant

Hurdle equation	Single-hurdle model		Double-hurdle model	
	Coefficient	S.E.	Coefficient	S.E.
Landowner and parcel characteristics				
Soil rental rate	1.69***	0.65	1.30	1.72
% income from farming	0.37***	0.11	0.35	0.23
Senior (yes=1)	0.65***	0.05	0.67***	0.13
Rent (yes=1)	-0.05	0.06	0.01	0.12
College degree (yes=1)	-0.26***	0.06	-0.27**	0.13
Risk averse (yes=1)	0.49***	0.06	0.47***	0.14
Current program enrollee (yes=1)	-0.77***	0.14	-0.83***	0.32
Current self-funder (yes=1)	-0.60***	0.07	-0.62***	0.15
No government monitoring (yes=1)	0.53***	0.06	0.55***	0.13
No farm support programs (yes=1)	0.36***	0.07	0.39**	0.16
Constant	-0.90***	0.08	-0.95***	0.24

N = 552 landowners

p-value: *** p<0.01, ** p<0.05, * p<0.1

Hurdle Model Results: Second-Stage

Choice equation	Single-hurdle model		Double-hurdle model	
	Coefficient	S.E.	Coefficient	S.E.
Program attributes variables				
Forest (baseline: grass buffer)	-0.18	0.13	-0.18	0.14
Bonus payment (baseline: no delay)	0.40**	0.17	0.42**	0.19
Bonus payment × 2-year delay	-0.02	0.17	-0.03	0.18
Bonus payment × 5-year delay	0.00	0.17	-0.01	0.18
Annual payment (baseline: 5-year contract)	1.41***	0.39	1.41***	0.34
Annual payment × 10-year contract	0.35	0.37	0.33	0.31
Annual payment × 15-year contract	0.14	0.37	0.12	0.33
Landowner and parcel characteristics				
Soil rental rate	-1.78	2.46	-2.06	1.69
% income from farming	-0.43*	0.29	-0.50*	0.29
Senior (yes=1)	0.04	0.13	0.05	0.14
Rent (yes=1)	0.35***	0.13	0.39***	0.13
College degree (yes=1)	-0.26*	0.15	-0.30**	0.14
Risk averse (yes=1)	-0.35**	0.16	-0.39**	0.17
Current program enrollee (yes=1)	0.10	0.24	0.11	0.26
Current self-funder (yes=1)	0.22	0.14	0.24	0.15
Constant	-0.06	0.34	-0.10	0.23

Number of choice-question observations: 2,021 p-value: *** p<0.01, ** p<0.05, * p<0.1

Implicit Discount Rates for Landowners

Expected indirect utility for landowner *i* from enrolling in program *j*, relative to status quo (no enrollment)

$$EV_{ij} = \alpha_i + \boldsymbol{X_i}\lambda + \delta z_{ij} + \beta_0 s_{ij} + \beta_2(s_{ij} \times D_2) + \beta_5(s_{ij} \times D_5)$$

$$+ \gamma_5 p_{ij} + \gamma_{10}(p_{ij} \times C_{10}) + \gamma_{15}(p_{ij} \times C_{15}) + \epsilon_{ij}$$

Average marginal rate of substitution (MRS) between the one-time bonus s_{ij} and the stream of constant annual payments p_{ij}. The MRS for baseline contract (5-year contract, signing bonus with no delay) is calculated as:

$$\frac{dp_{ij}}{ds_{ij}} = \frac{\hat{\beta}_0}{\hat{\gamma}_5}$$

Average MRS can be used to estimate average constant geometric discount rates *r*, where implicit discount rates are solved numerically from equations:

$$\frac{\hat{\beta}_0}{\hat{\gamma}_5} = \frac{r}{1 - (1+r)^{-5}}$$

$$\frac{\hat{\beta}_0}{\hat{\gamma}_5 + \hat{\gamma}_{10}} = \frac{r}{1 - (1+r)^{-10}}$$

$$\frac{\hat{\beta}_0}{\hat{\gamma}_5 + \hat{\gamma}_{15}} = \frac{r}{1 - (1+r)^{-15}}$$

Implicit Discount Rates for Landowners

Contract length	Logit model	Single-hurdle model	Double-hurdle model
5 years	27.7%	19.6%	20.6%
10 years	27.2%	20.0%	23.9%
15 years	13.8%	18.1%	19.4%

Part II:
Integrated assessment model & Policy scenarios

Integrated Assessment Model: Water Quality

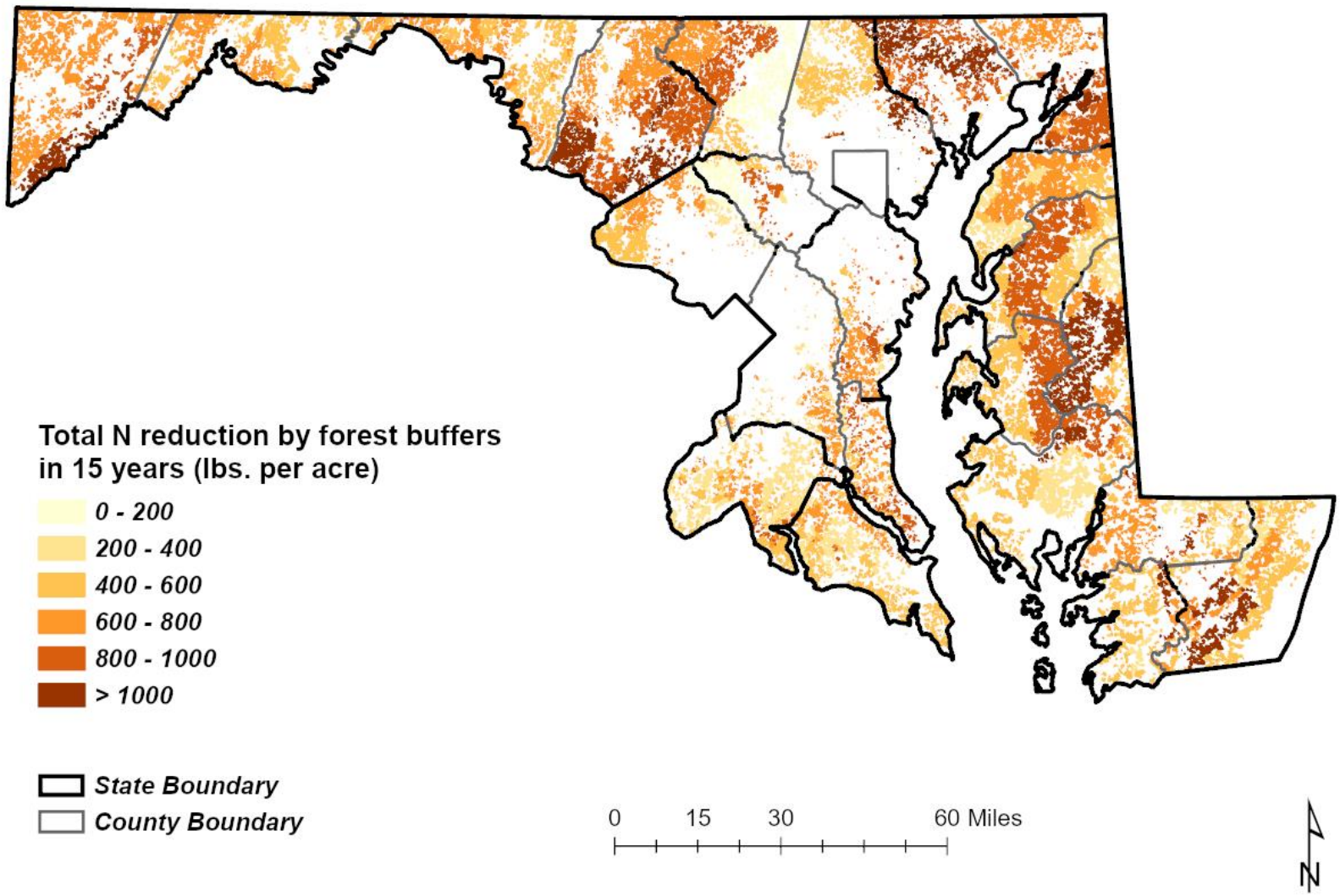
- **Buffer opportunities**
  - Identify riparian zone (35-foot width) without buffers using high-resolution land cover data (Chesapeake Conservancy)

- **Water quality model**
  - Parcel/farm-level estimates for nitrogen (N) and phosphorus (P) reductions for forest and grass buffers over specified contract length
  - Chesapeake Bay Watershed Model parameters
    - N and P loads for initial cropland and buffer type
    - Buffer practice efficiency on nutrient removal rates
    - Delivery factors from local watershed to the Bay

- **Environmental benefits for water quality**
  - Social cost of pollutant loads to the Bay estimated at $17.11 per pound N and $207.66 per pound P (Choi, Ready, and Shortle 2020)

Nitrogen Load Reduction

Forest buffer for 15-year contract

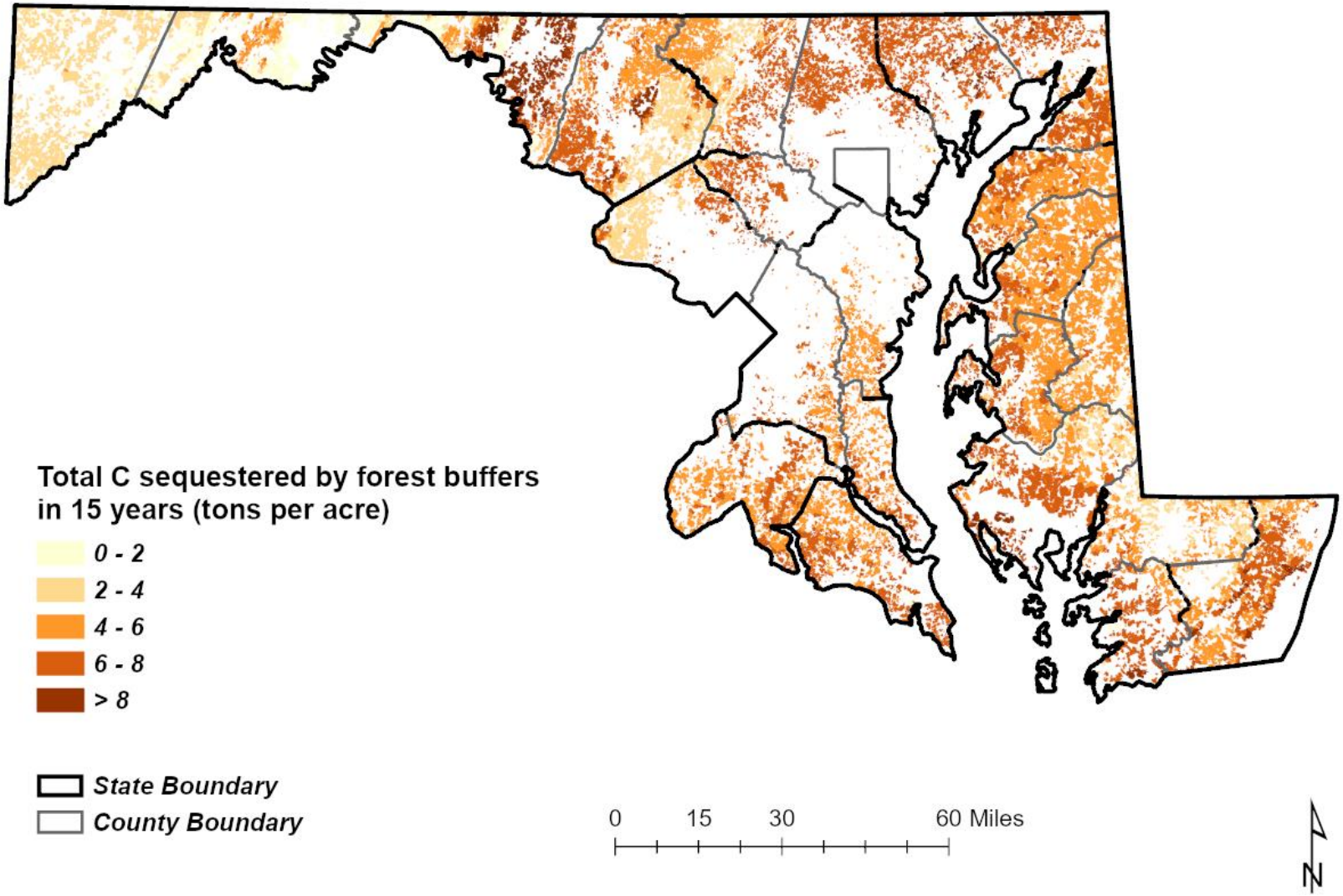


Integrated Assessment Model: Carbon

- **Carbon sequestration**
  - High-resolution forest carbon modeling for Maryland and northeast US (Hurtt et al. 2019; Lamb et al. 2021; Ma et al 2022)
  - Ecosystem Demography Model
    - Incorporates spatial and temporal variation in weather conditions (temperature, precipitation, etc.) and soil characteristics (depth, water retention, etc.)
    - Model estimates forest carbon storage (tons C per acre) at 30-meter resolution over time
  - Parcel/farm-level estimates of carbon sequestration for above-ground biomass in forest buffers over specified contract length (e.g., 15-year contract)
- **Environmental benefits of carbon sequestration**
  - Social cost of carbon estimated at $418 per ton C for permanent storage (Carleton and Greenstone 2022; EPA 2023), but discounted for buffer contract length (e.g., 15 years)

Carbon sequestration

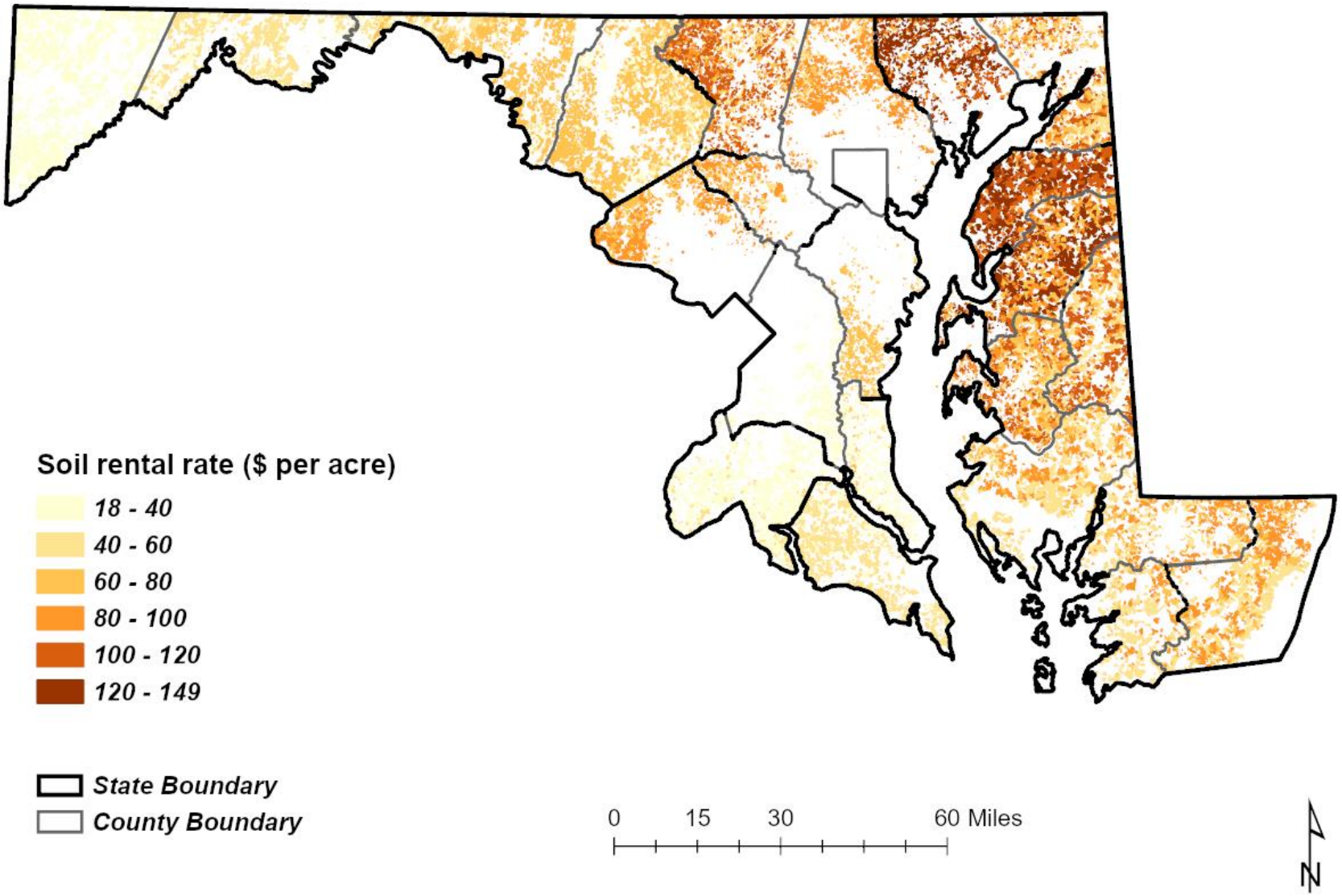
Forest buffer for 15-year contract



CREP (Baseline Scenario)

- **Contract length**
  - Forest buffers: 15 years
  - Grass buffers: 10 years
- **Annual recurring payments based on soil rental rate**
  - Forest buffers = 3*soil rental rate
  - Grass buffers = 2.5*soil rental rate
- **Installation costs fully paid (100% cost-share)**
  - Forest buffer (avg.) = $2,185/acre
  - Grass buffer (avg.) = $330/acre
    - Average installation costs from UMCES report (Price, Flemming, & Wainger 2019)
- **Upfront signing bonus**
  - Forest buffers = $1000/acre
  - Grass buffers = $200/acre

Parcel-Specific Soil Rental Rate



Policy Scenarios

Policy Scenario	Summary Description

Baseline CREP	• Full (100%) cost-share for buffer installation
	• Signing bonus upfront = $1,000/acre (forest); $200/acre (grass)
	• Annual rental payment based on parcel soil rental rate (SRR)
	  o Forest buffer: 3*SRR for 15-year contract
	  o Grass buffer: 2.5*SRR for 10-year contract for grass

All payments upfront	• Same as Baseline CREP, except convert present value of annual rental payment into a single upfront payment

Shorter contract lengths	• Same as Baseline CREP, except shorter contract length
	  o Forest buffer: 10-year contract
	  o Grass buffer: 5-year contract

Targeted bonus payments	• Same as Baseline CREP, except change signing bonus from uniform $1,000/acre to a targeted payment that varies spatially by the site-specific N reductions achievable on each parcel
Baseline CREP, plus carbon offset payments	• Same as Baseline CREP, plus additional payments for carbon sequestration storage over contract length (forest buffers only)

Modeling Landowner's Program Enrollment Decision

Logit model is used for predicted probability of landowner enrollment for all policy scenarios.

Logit and two-stage hurdle models provide similar predicted probability of landowner enrollment within range of CREP payments offered, despite different model specifications.

- $\hat{P}_{ij}(\theta_{ij}, X_i; \hat{\beta})$: Logit estimated probability of landowner i establishing riparian buffers under program j
  - θ_{ij}: A vector of program attributes in program j
  - X_i: A vector of characteristics of landowner i and farm operation
  - $\hat{\beta}$: Est. enrollment response to program attributes (stated preference study)

Simulated Policy Outcomes

Participation rate:

$$\overbrace{\underbrace{\frac{\sum_i \hat{P}_{ik} l_i}{\sum_i l_i}}_{\text{Total program-eligible acres}}}^{\text{expected acre enrolled under program } k}$$

Environmental benefits:

$$\sum_i \underbrace{\sum_{t=0}^{T_k-1} \delta^t \left(B_{it}^{carbon} + B_{it}^{water} \right) \overbrace{\hat{P}_{ik} l_i}^{\text{acres enrolled for parcel } i}}_{\text{NPV of env benefits from parcel } i}$$

Costs for program k:

$$\sum_i \underbrace{\sum_{t=0}^{T_k-1} \delta^t C_{it}^k \overbrace{\hat{P}_{ik} l_i}^{\text{acres enrolled for parcel } i}}_{\text{NPV of payments for parcel } i}$$

l_i: Program-eligible acres in landowner i's parcel

T_k: Contract length in program k

δ: discount factor

Policy Scenarios

Forest Buffer (Baseline: 15-year contract)

	Baseline CREP	All payments upfront	Shorter contract lengths	Targeted bonus payments	CREP + carbon payment
Participation rate					
% of landowners	16.4%	27.9%	17.3%	17.3%	17.5%
Total benefits and costs ($ in millions)					
Total benefits	2.36	4.04	1.71	2.60	2.53
Total costs	1.23	2.15	1.12	1.32	1.36
Net benefits	1.13	1.89	0.58	1.28	1.17
Benefit/cost ratio	1.91	1.88	1.52	1.96	1.86
Benefit decomposition (% of total benefits)					
N benefits	84%	85%	85%	85%	84%
P benefits	14%	13%	14%	13%	14%
C benefits	2%	2%	1%	2%	2%

CREP vs Carbon trading:
Representative (average) landowner
Forest buffer in 15-year contract

Carbon trading

- Regional Greenhouse Gas Initiative (RGGI)
  - RGGI trading price = $35/ton C
- Annual payment (avg.) for carbon sequestration
  - Annual carbon storage in forest buffer (avg.) = 0.38 tons C/acre
  - Annual payment = (0.38 tons C/acre)*($35/ton C) = $13/acre

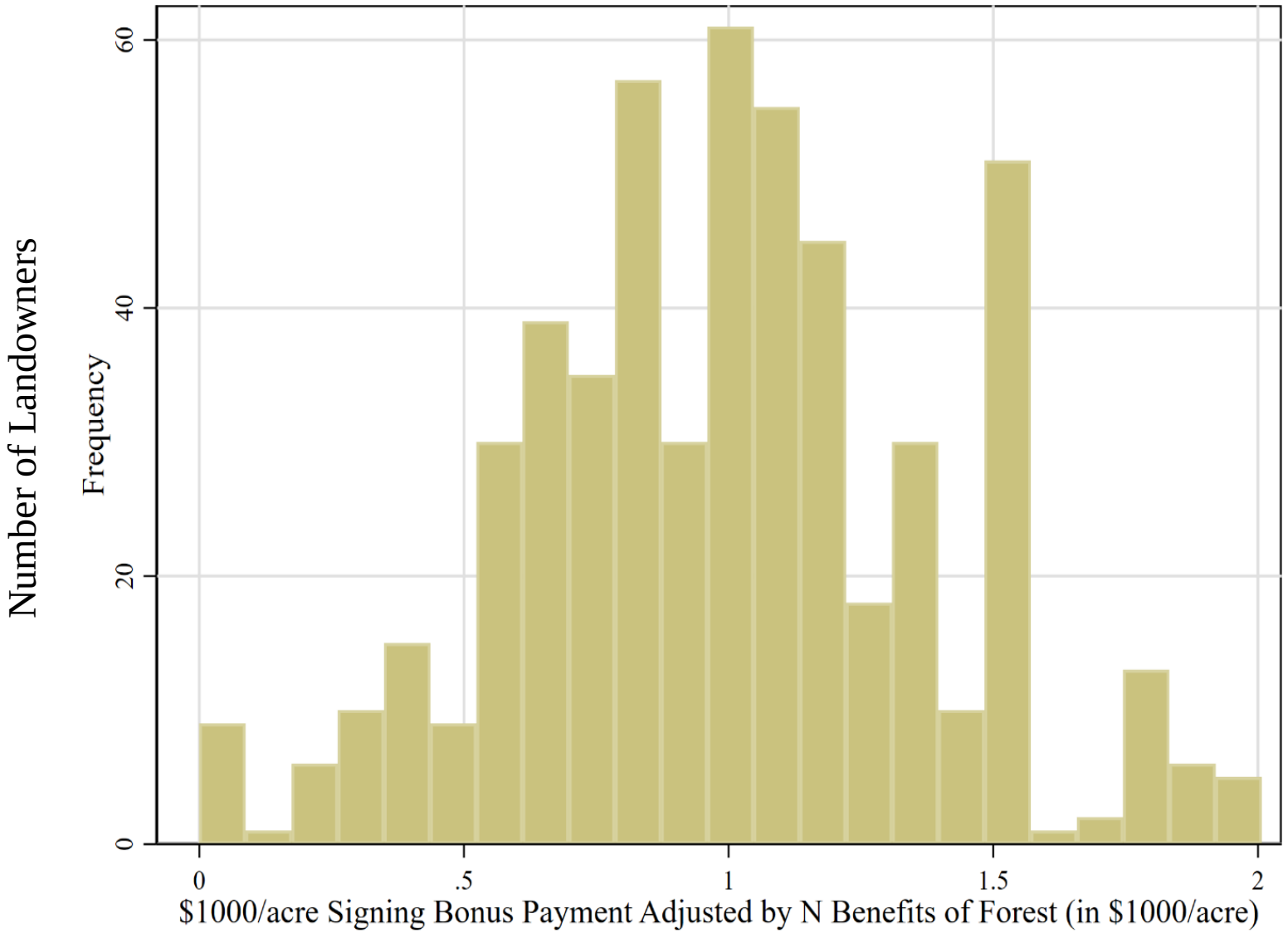
CREP

- Soil rental rate (avg.) = $77/acre
- CREP annual payment (avg.) = 3*SRR = $231/acre

Payment ($/acre)	**CREP**	**Carbon trading**
Cost-share installation	$2,100	$0
Signing bonus	$1,000	$0
Present value of annual payments for 15 years (discounted at 2.5%)	$2,932	$170
Total payments ($/acre)	$6,032	$170

Targeted signing bonus for forest buffer

Scaled by N benefits (average = $1,000/acre)



Policy Scenarios

Grass Buffer (Baseline: 10-year contract)

	Baseline CREP	All payments upfront	Shorter contract lengths	Targeted bonus payments
Participation rate				
% of landowners	6.0%	14.6%	4.9%	5.7%
Total benefits and costs ($ in millions)				
Total benefits	0.427	1.037	0.173	0.410
Total costs	0.176	0.437	0.090	0.165
Net benefits	0.252	0.600	0.083	0.245
Benefit/cost ratio	2.43	2.37	1.92	2.48
Benefit decomposition (% of total benefits)				
N benefits	92%	93%	92%	92%
P benefits	8%	7%	8%	8%
C benefits*	NA	NA	NA	NA

Estimated C benefits for grass buffers are not available.

Conclusions

- **Upfront payments are strongly preferred to annual payments**
  - Landowners have high discount rates (~14% to 28%) on average, compared to government agencies with much lower discount rates (bond loan rates)
  - Increased enrollment when shifting to upfront payments (in lieu of annual payments)

- **Shorter contract periods**
  - Limited effect on enrollment
  - Lower program net benefits

- **Carbon offset payments**
  - CREP is extremely generous, compared to carbon offset payments
  - Best-case scenario for trading because it often has higher transaction costs (Fisher-Vanden and Olmsted 2013; Palm-Forster et al. 2016)

Working papers

- **"Designing Contracts for Payment for Ecosystem Service Programs: Insights from a Stated Preference Survey"** (Lichtenberg, Newburn & Wang)
  - Household survey, DCE, hurdle models, implicit discount rates
  - Available SSRN, ResearchGate, Newburn personal website

- **"Emissions Trading Programs for Afforestation: Interactions with Federal Agricultural Conservation Programs"** (Kim, Newburn, Lichtenberg, Wietelman & Wang)
  - Economic model and integrated assessment model (water quality & carbon)
  - Programs in isolation vs. competition
    - Water quality trading (Pay for performance)
    - CREP (Pay for effort)
  - Research questions:
    - Have federal conservation subsidies crowded out water quality trading?
    - How much does stacking carbon payments with water quality payments increase the competitiveness of emission trading?
  - Available in summer 2025

"Payments and Penalties for Ecosytem Services Programs"

Kim, Lichtenberg, and Newburn (2024), *JEEM*

- **Standard penalty for early contract termination**
  - Landowner must pay back all money received, plus interest
  - Exists for all USDA Conservation Programs (CRP, CREP, EQIP) & PES programs in other countries/regions (UK, EU, Mexico, Costa Rica, Australia, among others).

- **Standard penalty is directly tied to payments**
  - Increased payments lead to higher enrollment
  - But also, indirectly leads to higher penalties that inhibit enrollment

- **Optimal penalty**
  - Based on environmental benefits for remaining contract years (forward looking)
  - Not based on payments already received (backward looking)

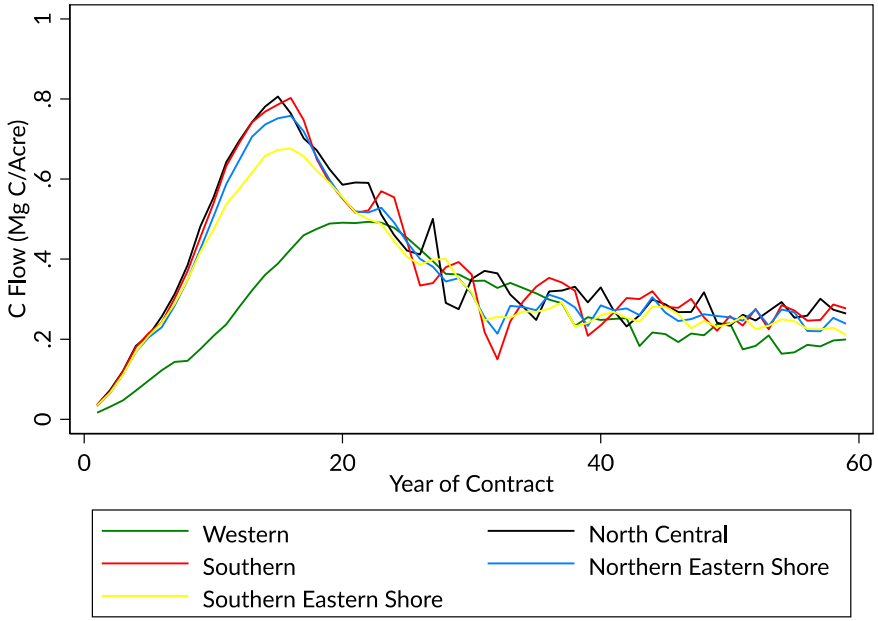
- **Forest buffers are more challenging than grass buffers**
  - Forest buffers have higher payments → higher penalties
  - Higher physical costs for forest buffer removal

Additional Slides

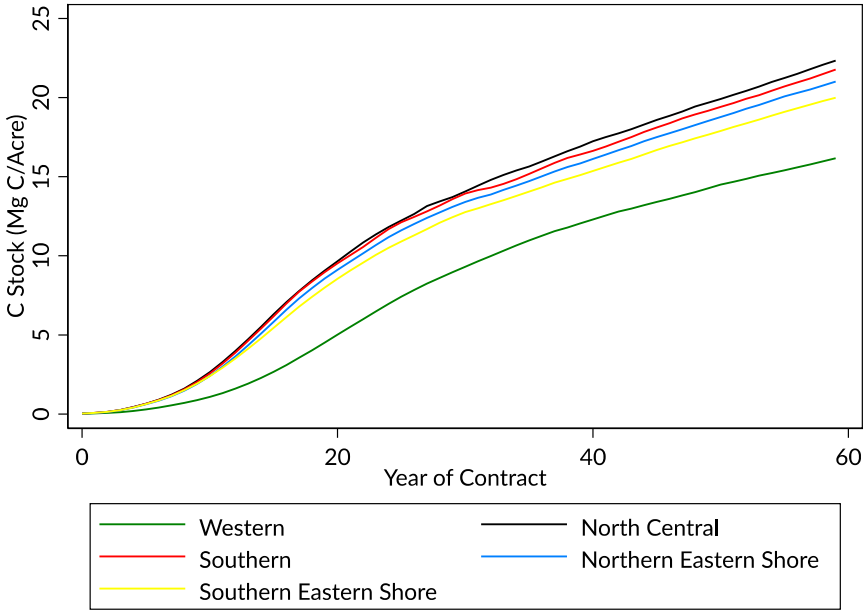
Forest carbon modeling

High-resolution forest carbon modeling for Maryland
(Hurtt et al. 2019; Lamb et al. 2021; Ma et al 2022)

Annual carbon sequestration rate
(metric tons C/acre) by MD region



Total carbon storage over time
(metric tons C/acre) by MD region

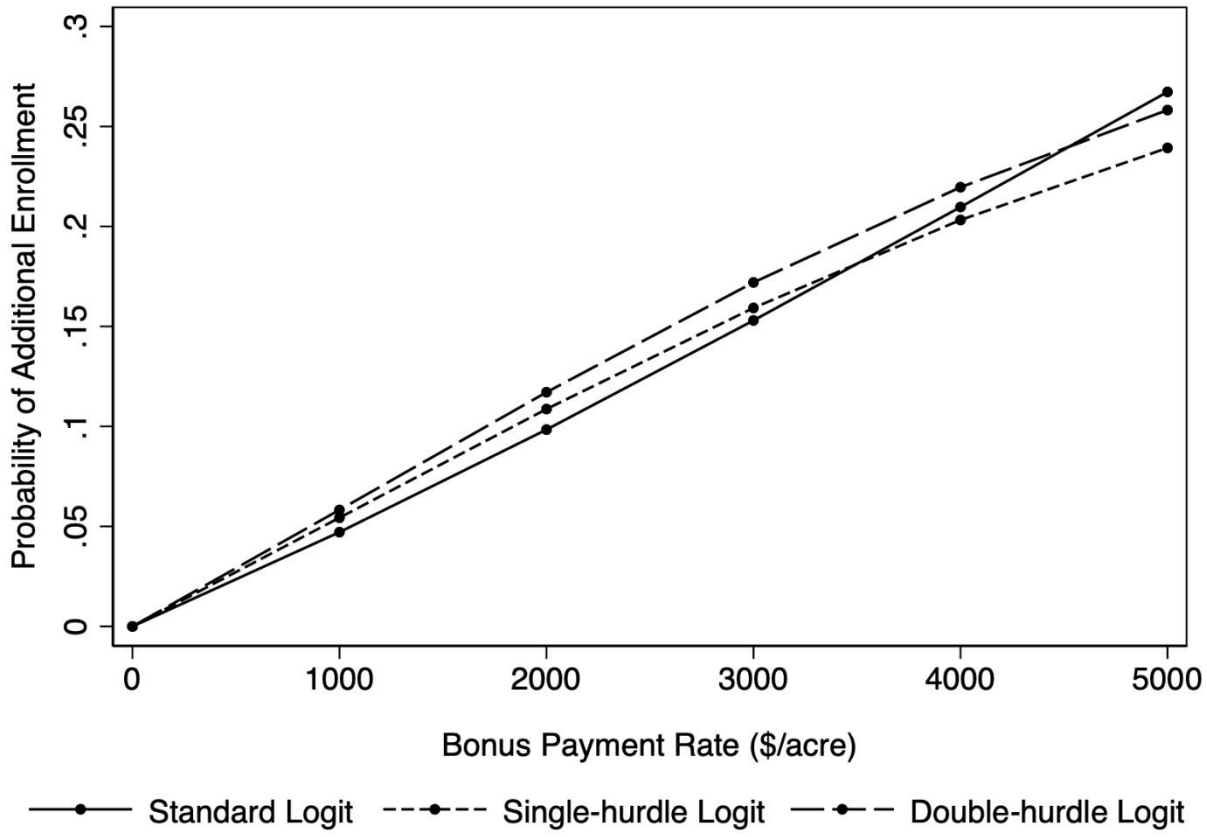


Riparian Buffer History

	Forest buffers		
	Pre-1998	1998-2009	2009-2021
Enrolled in cost-share program	25	61	37
Self-funded	429	49	38
% buffers enrolled	5.5%	55.5%	49.3%
	Grass buffers		
	Pre-1998	1998-2009	2009-2021
Enrolled in cost-share program	38	54	44
Self-funded	217	70	35
% buffers enrolled	14.9%	43.5%	55.7%
N=1,468 landowners in total			

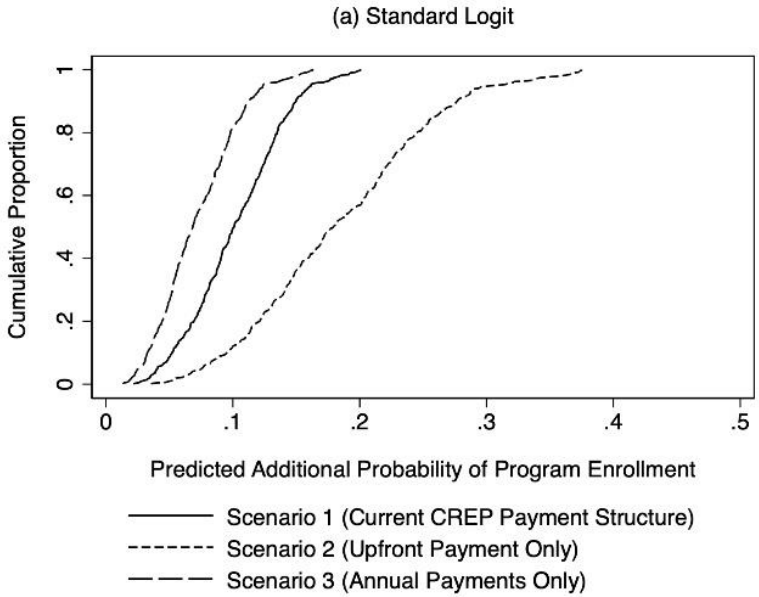
Predicted Probabilities of Additional Enrollment

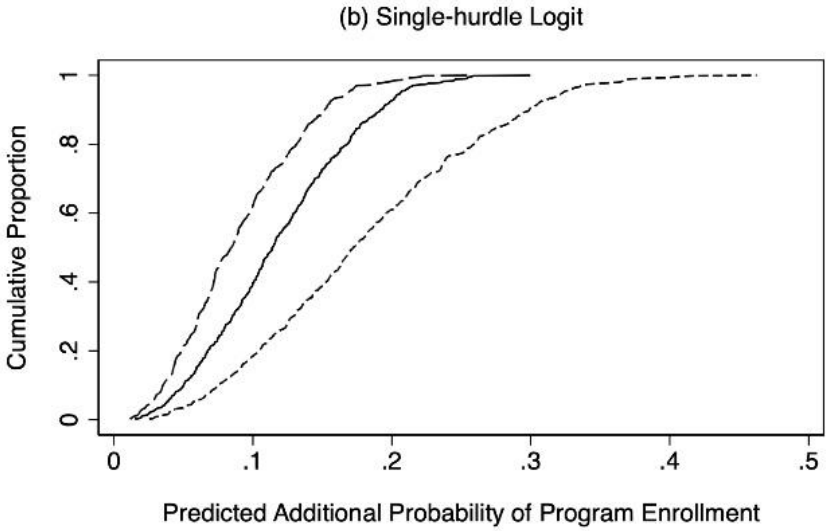
Forest buffer for 15-year contract

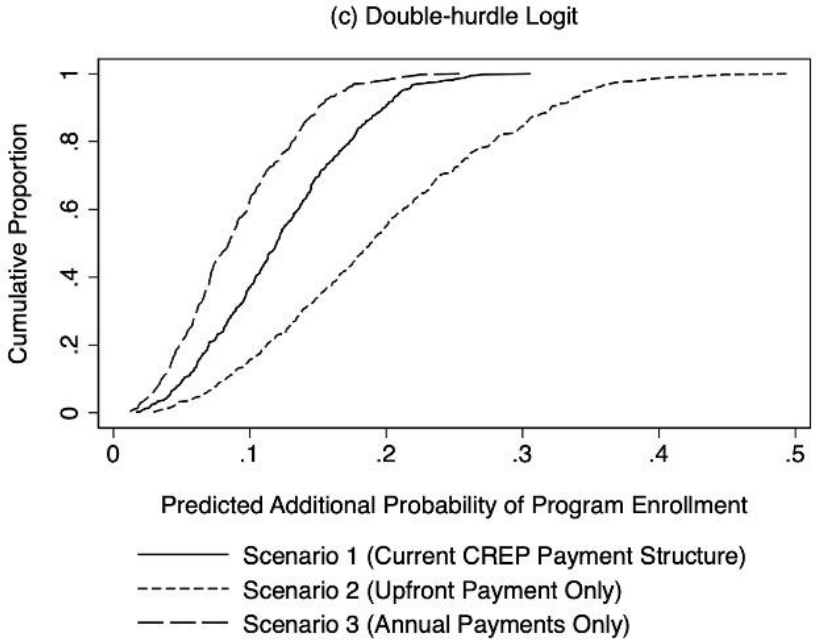


Predicted Probabilities of Additional Enrollment

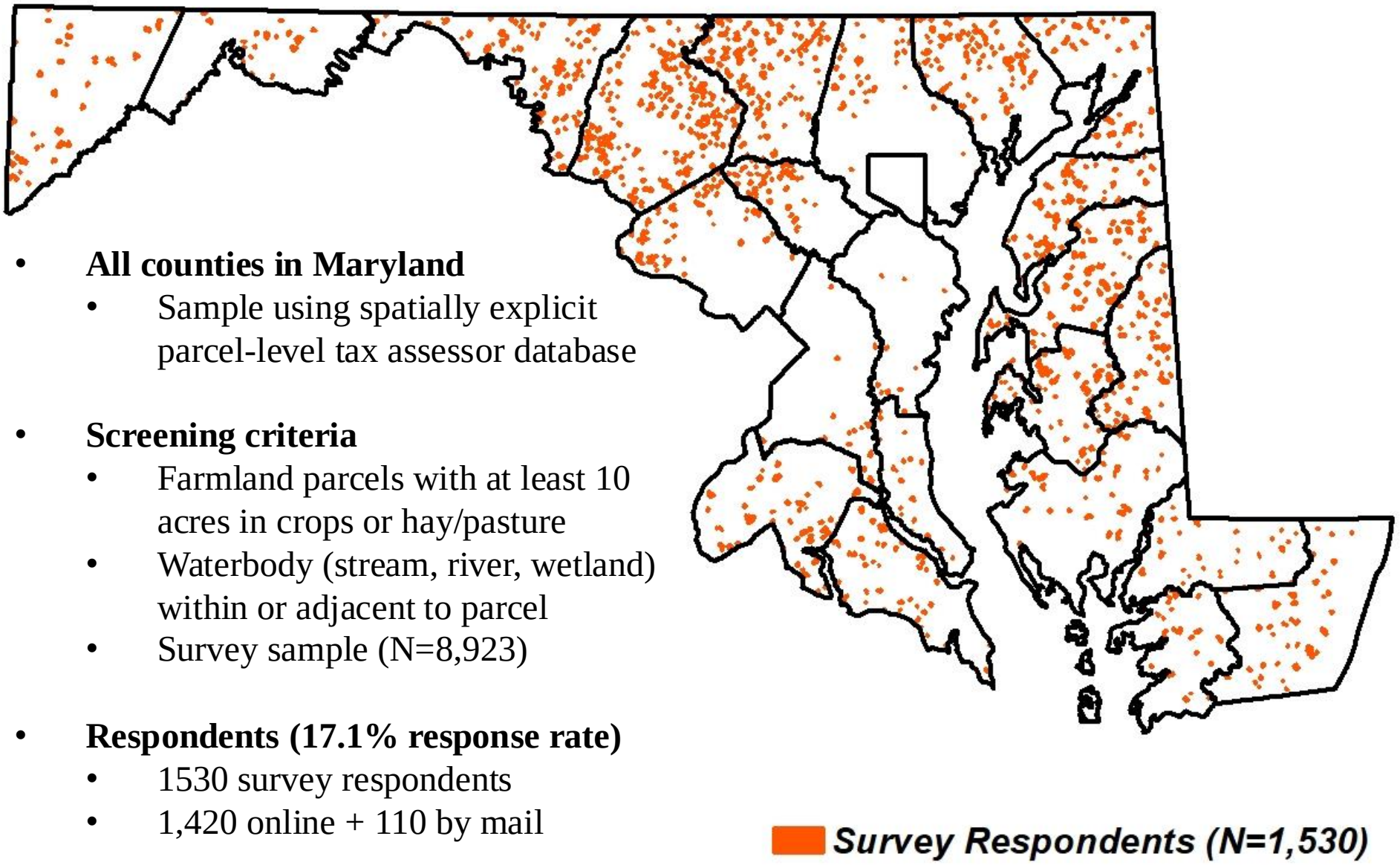
Forest buffer for 15-vear contract







Survey Respondents



- **All counties in Maryland**
  - Sample using spatially explicit parcel-level tax assessor database
- **Screening criteria**
  - Farmland parcels with at least 10 acres in crops or hay/pasture
  - Waterbody (stream, river, wetland) within or adjacent to parcel
  - Survey sample (N=8,923)
- **Respondents (17.1% response rate)**
  - 1530 survey respondents
  - 1,420 online + 110 by mail