

Payments and Penalties in Ecosystem Services programs

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Payments for Ecosystem Services (PES)

- **Financial incentives** in return for voluntary provision of **ecosystem services**

United States

- Conservation (Enhancement) Reserve Program (CRP and CREP), Environmental Quality Incentives Program (EQIP), and Conservation Stewardship Program (CSP)

EU

- Agri-environmental schemes (AES)

China

- Sloping Land Conversion Program (SLCP)

Costa Rica

- Pagos por Servicios Ambientales (PSA) program

United Nations

- Reducing Emissions from Deforestation and forest Degradation (REDD+)

- General features of the PES program
 - Medium- to long-term contract (5-20 years)
 - One-time upfront payment plus a series of annual payments
 - **Non-completion penalty:** total **payments received** + fixed fees (e.g., CRP and CREP)

Research Objectives: Optimal Penalty Structure

- How should the government structure penalties for contract non-completion in the PES programs?
- **Theoretical analysis:** Qualitative difference between optimal and standard penalty structures
- **Numerical policy simulation:** Magnitudes of differences between the two penalty structures and improvements in policy outcomes
- ✓ **Preview of findings**
 - Fundamentally different optimal and standard penalty structures
 - Potentially large inefficiencies from coupling penalty with total payments received

Focusing on the penalty and contract performance

- Existing studies mainly focus on **payments, participation**, and cost-effectiveness of the PES program (Alix-Garcia & Wolff, 2014; Jack et al., 2008; Ribaudo & Shortle, 2019; Wunder et al., 2020)
 - Hidden information and additionality (Claassen et al., 2018; Fleming et al., 2018; Horowitz & Just, 2013; Lichtenberg, 2021; Lichtenberg & Smith-Ramirez, 2011; Mason & Plantinga, 2013; Mezzatesta et al., 2013; Wu & Babcock, 1996)
 - Restructure payments (Ferraro, 2008; Suter et al., 2008)
 - Auction (Hellerstein et al., 2015; Palm-Forster et al., 2016)
 - Targeting based on performance (Babcock et al., 1997; Ferraro & Simpson, 2002; Savage & Ribaudo, 2016; Talberth et al., 2015)
 - Moral hazard in participation decision (Pates & Hendricks, 2020)
 - Exceptions: contract enforcement via costly *ex post* monitoring (Fraser, 2002; Hart & Latacz-Lohmann, 2005; Lankoski et al., 2010; Peterson et al., 2015)
- ✓ This paper focuses on participant performance
 - **Non-completion penalty** and **contract contract completion** after the initial signup

Multi-period PES Contract

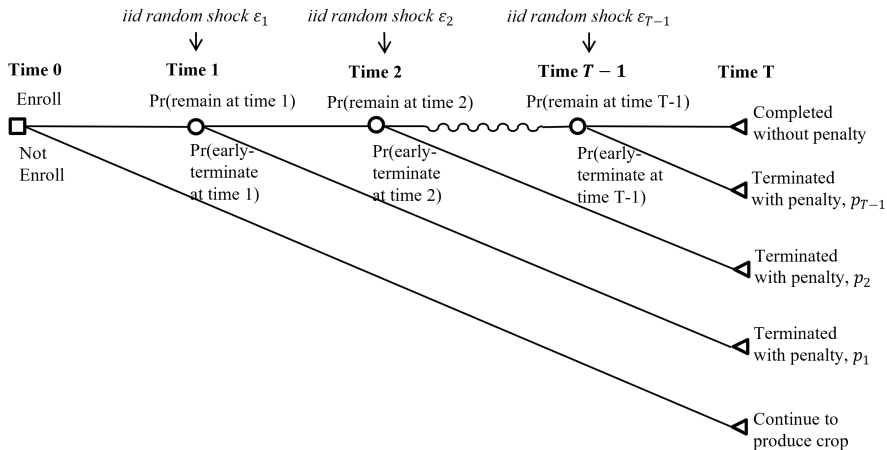


Figure 1: Land-use path during the contract periods

Participation constraint of a risk-neutral farmer

- Expected program return at least as great as expected net crop return during the contract period:

$$\begin{aligned}
 D_T \equiv & \underbrace{\text{Upfront payment net of installation cost}}_{a - k} + \underbrace{\text{Expected program return from completion}}_{\left(\prod_{t=1}^{T-1} F_t \right) \left(\sum_{t=1}^T \delta^{t-1} r \right)} \quad (1) \\
 & + \underbrace{\sum_{j=0}^{T-2} \left\{ \left(\prod_{t=0}^j F_t \right) \int_{L_{j+1}}^{\infty} \left[\sum_{l=0}^j \delta^l r + \left(\sum_{q=j+1}^{T-1} \delta^q v_q \right) \varepsilon_{j+1} - \delta^{j+1} (p_{j+1} + c_{j+1}) \right] f(\varepsilon_{j+1}) d\varepsilon_{j+1} \right\}}_{\text{Expected program return from non-completion}} \\
 \geq & \underbrace{\sum_{t=0}^{T-1} \delta^t v_t}_{\text{Expected net crop return}}
 \end{aligned}$$

p_t : early-termination penalty at time t

a : upfront payment

k : practice installation cost

v_t : expectation on crop return at time t

F_t : remaining probability at time t

δ : a discount factor

r : annual program payment

L_t : exit threshold level of random shock at time t

ε_t : i.i.d random shock at time t with density $f(\cdot)$

c : practice removal cost at time t

Government's Optimization Problem

- Chooses upfront payment a and penalty schedule p_t to maximize time 0 expected net program benefits (= environmental benefits – upfront payment – total annual payments + penalty revenue).

$$\begin{aligned}
 \max_{a, p_1, p_2, \dots, p_{T-1}} W_T \equiv & \underbrace{\text{Upfront payment}}_{-a} + \overbrace{\left(\prod_{t=1}^{T-1} F_t \right) \left(\sum_{t=0}^{T-1} \delta^t (B_t - r) \right)}^{\text{Net program benefits from completion}} \\
 & + \underbrace{\sum_{j=0}^{T-2} \left\{ \left(\prod_{t=0}^j F_t \right) (1 - F_{j+1}) \left[\sum_{l=0}^j \delta^l (B_l - r) + \delta^{j+1} p_{j+1} \right] \right\}}_{\text{Net program benefits from non-completion}}, \quad (2)
 \end{aligned}$$

subject to participation constraint in equation (1).

- Assumptions
 - exogenously determined r , k , and c ; i.i.d. ε_t ; adjustable $a \geq 0$ and $p_t \geq 0$
 - B_t , v_t , and $f(\varepsilon_t)$ known to the government at time 0

p_t : early-termination penalty at time t

B_t : environmental benefits at time t

a : upfront payment

r : annual program payment

F_t : remaining probability at time t

δ : a discount factor

Result 1. Optimal and standard penalties are qualitatively different in setting their **levels**

- **Optimal** penalty = **future net environmental benefits** lost (**forward-looking**)

$$p_t^* = \frac{1}{\delta^t} \left[\sum_{j=t}^{T-1} \delta^j (B_j - r) \right], \quad 1 \leq t \leq T-1. \quad (3)$$

- **Standard** penalty = total program **payments already paid** (**backward-looking**)

$$p_t^0 = \frac{1}{\delta^t} \left[a^0 + \left(\sum_{j=0}^{t-1} \delta^j r \right) \right], \quad (4)$$

B_t : environmental benefits at time t

r : annual program payment

a^0 : upfront payment under the standard penalty structure

δ : a discount factor

Result 2. Optimal and standard penalties are qualitatively different in setting their **trends**

- **Optimal** penalty generally **decreases** over time (government's rationality condition):

$$\delta p_{it+1}^* - p_t^* = -(B_t - r) < 0. \quad (5)$$

- **Standard** penalty monotonically **increases** over time:

$$\delta p_{it+1}^0 - p_t^0 = r > 0. \quad (6)$$

B_t : environmental benefits at time t

r : annual program payment

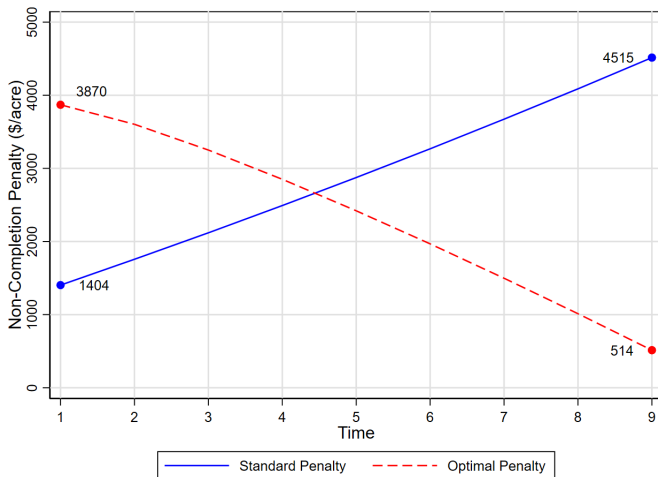
δ : a discount factor

Policy Simulation Outline

- **Objective:** Magnitudes of differences between the two penalty schedules and improvements in net program benefits
- A **representative corn farmer** in the Chesapeake Bay watershed
 - Crop return v_t : \$409/acre (Maryland Crop Budget 2021)
- PES contract converts **cropland** to **grass riparian buffer** for **10 years**
 - Annual payment r : \$306/acre (CREP in Maryland: USDA-FSA)
 - Upfront payment a : set to ensure farmer's program participation
- **Environmental benefits:** reduction of nutrients and sediments runoff delivered to the watershed (\$ value)
 - Water quality benefits B_t : \$519–\$820/acre (Belt et al. (2014), Choi et al. (2020), and Hairston-Strang (2005) and Chesapeake Bay Watershed Model)

Result 3. Optimal and standard penalties are **quantitatively** different

Figure 2: Non-completion penalty schedule



Result 4. Inefficiencies from the standard penalty structure can be substantial

- Government's net program benefits (NPBs) = environmental benefits – upfront payment – total annual payments + penalty revenue

Table 1: Government's Net Program Benefits

Penalty	Upfront Payment (\$/acre)	Env. Benefits (\$/acre)	Total Annual Payment (\$/acre)	Penalty Revenue (\$/acre)	NPBs (\$/acre)
Optimal	1,232	6,636	2,694	37	2,748
Standard	1,060	4,992	2,056	431	2,307
Difference	172	1,644	638	-394	441

- 19% increase in net program benefits under the optimal penalty structure (robust under a range of parameter values)

Implications for the Payments for Ecosystem Services (PES) Contract Design

1. The optimal penalty structure is **qualitatively** and **quantitatively** different from the current standard penalty structure.
2. Government may increase net environmental benefits from the PES contract substantially by **restructuring** the current standard penalty.

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