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

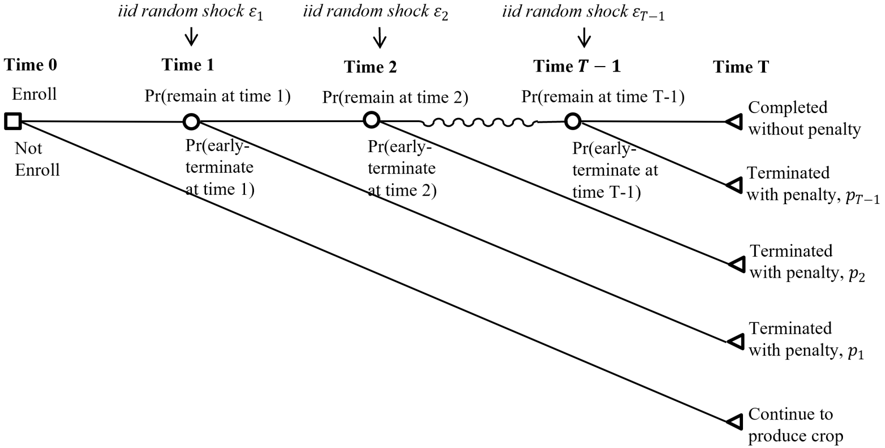


Figure 1: Land-use path during the contract periods

Participation constraint of a risk-neutral farmer

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

$$D_T \equiv \overbrace{a-k}^{\text{Upfront payment net of installation cost}} + \overbrace{\left(\prod_{t=1}^{T-1} F_t\right)\left(\sum_{t=1}^{T} \delta^{t-1} r\right)}^{\text{Expected program return from } \textbf{completion}} \tag{1}$$

$$+ \underbrace{\sum_{j=0}^{T-2}\left\{\left(\prod_{t=0}^{j} F_t\right)\int_{L_{j+1}}^{\infty}\left[\sum_{l=0}^{j}\delta^l r + \left(\sum_{q=j+1}^{T-1}\delta^q v_q\right)\varepsilon_{j+1} - \delta^{j+1}(p_{j+1}+c_{j+1})\right] f(\varepsilon_{j+1})d\varepsilon_{j+1}\right\}}_{\text{Expected program return from } \textbf{non-completion}}$$

$$\geq \underbrace{\sum_{t=0}^{T-1}\delta^t v_t.}_{\text{Expected net crop return}}$$

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).

$$\max_{a,p_1,p_2,\dots,p_{T-1}} W_T \equiv \overbrace{-a}^{\text{Upfront payment}} + \overbrace{\left(\prod_{t=1}^{T-1} F_t\right)\left(\sum_{t=0}^{T-1} \delta^t (B_t - r)\right)}^{\text{Net program benefits from } \textbf{completion}} \tag{2}$$

$$+ \underbrace{\sum_{j=0}^{T-2} \left\{ \left(\prod_{t=0}^{j} F_t\right)(1 - F_{j+1})\left[\sum_{l=0}^{j} \delta^l (B_l - r) + \delta^{j+1} p_{j+1}\right]\right\}}_{\text{Net program benefits from } \textbf{non-completion}},$$

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

a: upfront payment

F_t: remaining probability at time t

B_t: environmental benefits at time t

r: annual program payment

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)

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

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

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

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:

$$\delta p^0_{it+1} - p^0_t = r > 0. \quad (6)$$

B_t: environmental benefits at time t

r: annual program payment

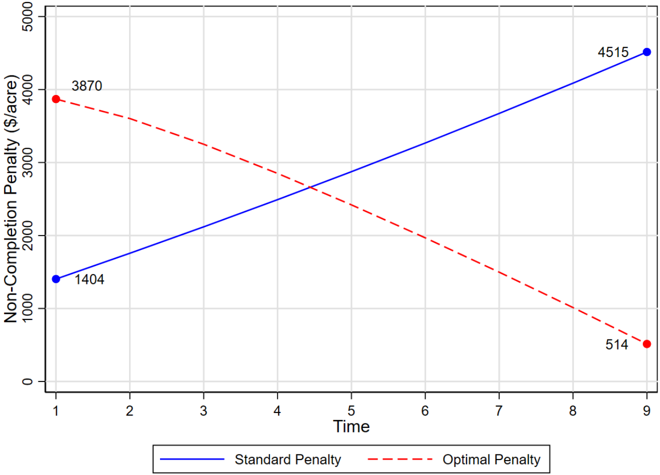
δ: a discount factor

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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