Property Rights with Biological Spillovers: when Hardin meets Meade

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**Hardin (Property rights)**

- Hardin (1968): the tragedy of the commons
  - ecological tragedy: "Freedom in a commons brings ruin to all" (Hardin, p.16)
  - Reasonable solutions:
    - sell pasturage off as a private property
    - keep it as a public property and allocate property rights
- Unanswered questions:
  - to whom should property rights be allocated?
  - how many property rights should be allocated?
Decentralization:

- since the mid-80’s decentralization management of natural resources has become a global movement
- decentralization theorists claim that decentralization "improve efficiency and equity" (Larson and Ribot, 2004) in terms of:
  - more intimate knowledge of the resource
  - lower maintenance costs
- However over-exploitation of the natural resource (ex Uganda, Indonesia, ...)

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Meade (Biological spillovers)

- Meade (1952): beekeeper next to apple orchard. pollination/nectar: positive externalities
Model in which:

- Well defined property-rights regime (common property regime).
- Biological spillovers across parcels.

such that:

- The boundaries of private titles and the boundaries of the impacts of resource use may not coincide.
- The dynamics of the resource are influenced by the property-rights regime over it.
Objective:
Maximize the stock of the forest in the steady state: Which property-rights regime maximizes the stock of natural resource?

• Strategic framework
• Cooperative framework
The Model

- $D_t$: number of plots at time $t$. Each plot is assigned to a community that has property rights on it (harvesting) and must manage it (management costs). Communities are identical.
- Forest:
  \[ X_{t+1} = ((1 + b(D_t))X_t - Y_t)^\alpha \]
  \[ (1) \]
- where:
  - $X$: stock of the forest
  - $Y_t$: total extraction at time $t$. $Y_t = \sum_{i=1}^{D_t} y_t^i$
  - $b(D_t)$: growth rate of the resource, depends on $D_t$
Assumptions on $b(\cdot)$

- $b(D_t) > 0 \ \forall D_t$
- $b'(\cdot) < 0 \ \forall D_t$
- $b(1) > D_t b(D_t) \ \forall D_t$
• OLG model: at each time $t$ a new born generation. Agents live 2 periods: youth and old age $\rightarrow$ overlapping generations
• In each community: one representative young and one representative old
• The young harvest while the old own capital
• Community’s extraction at time $t$:

$$y_t^i - h\left(\frac{X_t}{D_t}\right) = k_{t+1}^i + z_t^i$$  \hspace{1cm} (2)

where:

• $h\left(\frac{X_t}{D_t}\right)$: maintenance (monitoring) costs at time $t$, depends on $D_t$

• $k_{t+1}^i$: harvest saved as capital

• $z_t^i$: harvest used as an input for current production
Assumptions on $h(\cdot)$

We define $x_t = X_t / D_t$ the stock of forest in each plot at time $t$

- $h(.) > 0 \forall D_t$
- $h'_{x_t} > 0 \forall D_t$
- $h \left( \frac{X_t}{1} \right) > D_t h \left( \frac{X_t}{D_t} \right) \forall D_t$
• Total extraction at time $t$

$$Y_t - D_t h(D_t, X_t) = K_{t+1} + Z_t$$  \hspace{1cm} (3)

• Both old and young use capital, $k$, and the natural resource, $z$, to produce the consumption good, $c$ using $G(k, z) = k^\beta z^{1-\beta}$. (market for $k$ and $z$)

• Agents utility is given by

$$u(c_{t}^{iy}) + u(c_{t+1}^{io})$$  \hspace{1cm} (4)
Sensitivity of the resource to the enforced property-rights regime: different resources have different ways to react to the same property-rights regime

- **Meade effect**: biological spillovers are strong, splitting the forest is always highly detrimental for its natural evolution.
- **Hardin effect**: the natural evolution of the forest is midly affected by the property rights-regime.

Meade and Hardin effect encompass:

- the balance between $b(\cdot)$ and $h(\cdot)$.
- the harvesting decision of the agents.
The maximization problem for the young agent is the following

\[
\max_{z_t^i, k_t^{i+1}} u(c_t^{iy}) + u(c_t^{io}) + u(c_t^{i+1}) \tag{5}
\]

s.t.

\[
X_{t+1} = \left[ X_t (1 + b(D_t)) - y_t^i - \sum_{j \neq i} y_t^j \right]^\alpha
\]
The steady state $X^*$

Solving the maximization problem we end up with

$$X_{t+1} = \left( \frac{\alpha(1 - \beta) \left[ X_t(1 + b(D_t)) - D_t h \left( \frac{X_t}{D_t} \right) \right]}{\alpha(1 - \beta) + (2D_t - 1)} \right)^\alpha$$

(6)

$D$ affects $X_{t+1}$ through different channels:
- effect due to the denominator
- contrasting effects on $b(D_t)$ and $h \left( \frac{X_t}{D_t} \right)$
Let assume that

\[ b(D_t) = a - cD_t^2 \quad a > cD^2 > 0 \]  \hspace{1cm} (7)

\[ h \left( \frac{X_t}{D_t} \right) = e \left( \frac{X_t}{D_t} \right) \quad e > 0 \]  \hspace{1cm} (8)

satisfying assumptions on \( b(\cdot) \) and \( h(\cdot) \).
We set $\alpha = \frac{1}{2}$, we plug (7) and (8) into (6) and we evaluate it at the steady state. One non trivial steady state, $X^*$:

$$X^* = \frac{D \left[ (cD^2 - a - 1)(1 - \beta) \right]}{D (1 - 4D + \beta) - e(1 - \beta)} \quad \text{with} \quad 0 < c < \frac{1 + a}{D^2} \quad (9)$$

Is $X^*$ increasing or decreasing in $D$? We still do not know.
We set the values for parameters $a$, $c$, and $\beta$ while let $e$ vary.

Proposition

Let $a = 20$, $c = 0.1$ and $\beta = 0.5$. Then, if $e \geq 74$ in the strategic equilibrium $X^*$ is first increasing and then decreasing in $D$. Otherwise, $X^*$ is always decreasing in $D$. 
Plot of $X^*$ when $e = 90$ (left) or $e = 0.1$ (right): Hardin vs Meade effects

Other parameters: $a = 20$, $c = 0.1$ and $\beta = 0.5$. $D \geq 2$
The number of communities $D_t$ is taken as given, but communities cooperate.

The max problem becomes:

$$\max_{z_t^i, k_{t+1}^i} u(c_t^{iy}) + u(c_{t+1}^{io})$$

subject to:

$$X_{t+1} = [X_t(1 + b(D_t)) - D_t y_t^i]^{\alpha}$$
• While in the symmetric Nash equilibrium $y^i = y^j$ and $z^i = z^j$ for any $i, j = 1, 2, \ldots, D$, in the cooperative setting $Y_t = D_t y^i_t$ and $Z_t = D_t z^i_t$

• Then eq (6) becomes

$$X_{t+1} = \left( \frac{\alpha(1 - \beta) \left[ X_t (1 + b(D_t)) - D_t h \left( \frac{X_t}{D_t} \right) \right]}{\alpha(1 - \beta) + 1} \right)^{\alpha}$$

(11)

• What are the effects of $D$ on $X_{t+1}$?
  • no effect through the denominator
  • contrasting effect on $b(.)$ and $h(.)$
We set $\alpha = \frac{1}{2}$, we plug (7) and (8) into (11) and we evaluate it at the steady state. One non trivial steady state, $X^C$:

$$X^C = \frac{D \left[ (cD^2 - a - 1) (1 - \beta) \right]}{D (\beta - 3) - e (1 - \beta)} \quad \text{with} \quad 0 < c < \frac{1 + a}{D^2}$$

(12)

Which effect of $D$ on $X^C$ does prevail? We still don’t know
We set the values for $a$, $c$ and $\beta$, while let $e$ vary.

**Proposition**

Let $a = 20$, $c = 0.1$ and $\beta = 0.5$. Then, if $e \geq 0.2$ in the cooperative equilibrium $X^C$ is first increasing and then decreasing in $D$. Otherwise, $X^C$ is always decreasing in $D$. 


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Plot of $X^C$ and $X^*$ when $e = 0.1$ (left) or $e = 90$ (right): Cooperative vs Strategic behaviour

Other parameters: $a = 20$, $c = 0.1$ and $\beta = 0.5$. $D \geq 1$
Plot of $X^C$ and $X^*$ when $e = 30$

Other parameters: $a = 20$, $c = 0.1$ and $\beta = 0.5$

$\Rightarrow$ Hardin and Meade effects depend on the balance between $b(\cdot)$ and $h(\cdot)$ as well as the harvesting decision of the agents.
Fiscal Policy: A lump-sum transfer

At time $t$ each community sets a lump-sum transfer, $\omega$, such that eq. (2) becomes

$$y^i_t - h\left(\frac{X^i_t}{D_t}\right) = k^i_{t+1} + z^i_t + \omega$$

(13)

**Objective:** Reproduce the cooperative outcome in the strategic setting.
Proposition

For any $D > 1$, there exists a $\omega^*(D)$

$$\omega^*(D) = -\frac{4(1 - \beta)D(D - 1)(1 + a - cD^2)^2}{(e(\beta - 1) + D(\beta - 3))^2}$$

such that it is possible to decentralize the cooperative equilibrium.
How to obtain the level $X_{max}^C$ in the strategic setting?

- $\omega^*(D)$ and play on $D$
- if it is not possible to change $D$, then...

**Corollary**

Let $D_{max}$ the value of $D$ for which the steady-state stock of resource, is maximized in the cooperative framework, $X_{max}^C$. Then, for any $D > 1$, there exists a $\hat{\omega}(D, D_{max})$

$$\hat{\omega}(D, D_{max}) = -\frac{4(1 - \beta)D_{max}(D - 1)(1 + a - cD_{max}^2)^2}{D(e(\beta - 1) + (D_{max}(\beta - 3)))^2}$$

such that it is possible to decentralize $X_{max}^C$. 

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Conclusions

- Model with common property rights and biological spillovers
- Maximize the stock of the forest in the steady state given the structure of the model:
  - Strategic framework
  - Cooperative framework
- Fiscal instrument to decentralize the cooperative outcome
- Fiscal instrument the maximum cooperative outcome (without changing $D$)
Thank you for your attention!