

Dynamic Conservation Contracts

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Some Quite Important Questions

- How should we conserve Nature?
 - Tropical forests are disappearing
 - Fossil fuel should be kept in the ground
 - We may have to compensate the owners/users....
 - ...but who/how/when/where?
- We don't know.
- First (?) paper on how to contract on reduced resource depletion.
(well...not yet a paper...but in progress)

Literature (preliminary)

- Harstad '12: First-best climate policy: pay countries for not extracting
 - Renting/contracts may be more reasonable: but how?
- Jehiel, Moldovanu, Stacchetti '96; JM '95a, '95b, '96: Sales in the presence of externalities
 - One seller/many buyers.
 - Here: many sellers/one "buyer"
- Segal '99: Contracting with externalities
 - but static model...
- Hotelling '31: Optimal depletion of exhaustible resource

Outline

- A Model of Extraction
- The First Best
- The Equilibrium
- Heterogenous stocks
- Policies and Comparative Static
- Robustness
- Limitations
- Conclusions

A Model of Extraction

- n resource owners (**agents**) possess stocks y_i^0 and extract x_i^t
- Each stock is exhaustible: $y_i^{t+1} = y_i^t - x_i^t$
- The market is common:

$$p^t = b - ax^t, \text{ where } x^t \equiv \sum_i x_i^t$$

- Utilities are transferable:

$$u_i^t = p^t x_i^t + s_i^t$$

- The principal prefers conservation

$$u_0^t = -ex^t - s^t + w \frac{a}{2} (x^t)^2, \text{ where } s^t \equiv \sum_i s_i^t$$

- Contracts $\mathbf{s}^t(\mathbf{x}^t)$, $\mathbf{x}^t = (x_1^t, \dots, x_n^t)$, $\mathbf{s}^t(\mathbf{x}^t) = (s_1^t(\mathbf{x}^t), \dots, s_n^t(\mathbf{x}^t)) \geq 0$.
- Starting assumption: Outside option is $x_i^t = y_i^t$.
- Reasonable if

$$y_i^t < \tilde{y} \equiv (1 - \delta) b / 2a.$$

0. The First Best

Proposition

- 1 *Sequence: Given x^t , x_i^t is irrelevant*
- 2 *Steady state: $y^T \equiv \sum_i y_i^T = 0$ if $b > e$, $y^T = y^0$ if $b < e$.*
- 3 *Speed: Marginal social revenue increases exponentially with discount factor δ*

$$b - e - a(2 - w)x^t = \delta [b - e - a(2 - w)x^{t+1}]$$

- Simplifies to the standard Hotelling rule if $w = 1$ and $e = 0$:

$$p^t = \delta p^{t+1}$$

- If $w = 0$, marginal sales revenue increases exponentially

1. Sequence of Extraction

Proposition

- *Only one stock is extracted from at each time*
- *The stocks with the **smallest sizes** are depleted first*
- Intuition: By increasing x_i^t , every other s_j^t can be reduced by ay_j^t .
- This cost-saving is largest when $\sum_{j \neq i} y_j^t$ is largest, i.e., when y_i^t is small.
- Furthermore: In steady state, $\sum_i s_i^t = \sum_i y_i^t (b - ay_i^t)$ is concave. Thus, it is more expensive to compensate a *large* number of wannabe monopolists, than to compensate one big
- Can order according to size, $y_1^0 \geq y_2^0 \geq \dots$ and $Y_i^t \equiv \sum_{j=1}^i y_j^t$

2. Steady State

Proposition

- A unique steady state is reached in finite time T .
- If $b > e$, $y^T = 0$, as in the first best
- If $b < e$, the $\hat{i}$ largest stocks are conserved where $\hat{i}$ satisfies

$$Y_{\hat{i}-1}^0 \leq \frac{e-b}{a} \leq Y_{\hat{i}}^0$$

- With a large number of small stocks ($y_{\hat{i}} \rightarrow 0$), the steady-state conservation level is

$$y^T = \max \left\{ 0, \frac{e-b}{a} \right\}.$$

2. Steady State

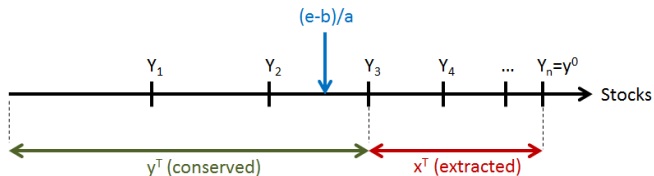


Figure: *The largest stocks are conserved, while the smallest stocks are depleted.*

3. Speed of Extraction

Proposition

- *The marginal social surplus increases more than exponentially in time.*
- *The speed is particularly large when $Y_{i-1}^0 \equiv \sum_{i=1}^{i-1} y_i^0$ is large*
- *For any two consecutive periods, we have:*

$$[b - e - a(2 - w)x^t] + aY_{i-1}^0 = \delta [b - e - a(2 - w)x^{t+1}]$$

- The outcome is first best if $n = 1$
- Otherwise, the speed of extraction is too high
- The extraction level x^t is piecewise concave in t , and the price p^t is piecewise convex in t .

3. Speed of Extraction

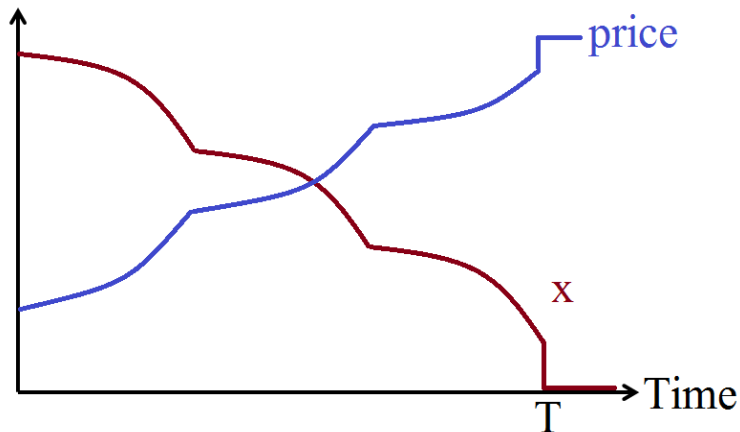


Figure: *The extracted quantity x , and the equilibrium price p , as functions of time.*

Heterogeneity - First Best

- Suppose marginal extraction costs are c_i and environmental harm e_i
- The first best is modified as follows

Proposition

- 1 *Sequence: Extract stocks with smallest $c_i + e_i$ first*
- 2 *Steady state: $y_i^T = 0$ if $c_i + e_i < b$, $y_i^T = y_i^0$ if $c_i + e_i > b$.*
- 3 *Speed: Marginal social revenue increases exponentially:*

$$-c_i - e_i - a(2 - w)x^t = \delta [b - c_i - e_i - a(2 - w)x^{t+1}]$$

Heterogeneity - Equilibrium

Proposition

- ① *Sequence: Extract stock i before stock j if*

$$y_i^0 + (c_i + e_i) (1 - \delta) / a \leq y_j^0 + (c_j + e_j) (1 - \delta) / a$$

- ② *Steady state: the $\hat{i}$ largest $y_i^0 + (e_i + c_i) (1 - \delta) / a$ are conserved where*

$$aY_{\hat{i}-1}^0 \leq e_{\hat{i}} + c_{\hat{i}} - b \text{ and } e_{\hat{i}+1} + c_{\hat{i}+1} - b \leq aY_{\hat{i}}^0$$

This condition is sufficient if the heterogeneity in $e_i + c_i$ is small:

$$(e_i - e_{i-1}) + (c_i - c_{i-1}) \notin (aY_{i-1}^0, (Y_{i-1}^0 - Y_i^0) (1 - \delta) / a) .$$

- ③ *Speed: Marginal social revenue increases more than exponentially:*

$$b - e_i - c_i - a(2 - w)x^t + aY_{i-1}^t = \delta [b - e_i - c_i - a(2 - w)x^{t+1}]$$

Policies and Comparative Static

- With m similar buyers with demand function $p^t = b - a_m x_m^t$, aggregate demand is $p^t = b - a x^t$ where $1/a = \sum_m 1/a_m$
- If some buyer(s) **boycott**, a increases
- Thus, a boycott has the following consequences:
 - ① Extraction may switch from cleanest/less expensive to smallest
 - ② Steady state conservation decreases
 - ③ Speed of extraction increases
- Intuition: Steeper demand curve makes it easy/tempting for the contract-provider to reduce the price.
- A **consumption tax** decreases b and leads to more conservation.

- It is indeed efficient to offer contracts to the largest tropical forest owners, such as Brazil and Indonesia, according to this theory
- However, the optimal contracts are highly asymmetric
- Harmonized contracts achieve too little conservation at a too large cost.

Long-Term Contracts (with Commitment)

- With commitment, payments can be delayed
- This relaxes incentive constraints in the meanwhile
- ...and then, there is no reason to raise x_i^t to lower s_j^t
- Outcome becomes first-best (after the very first period)
- If principal can ask for money up front, first-best also in first period.
- Long-term contracts lead to slower extraction and more conservation.

Robustness I: Outside Option

- Above we have assumed that the outside option is $x_i^t = y_i^t$
- This assumption is "crazy" (unless each period long/ δ is small)
- The outside option x_i^t should be to maximize i 's continuation value
- In general, x_i^t will then depend on all remaining stocks
 - We are struggling a bit with this...
- However, there may be capacity constraints on extraction
- Suppose the outside option is to extract x_i^t and leave $y_i^{t+1} = F(y_i^t)$
- Results continue to hold (qualitatively)

Robustness II: Protection Costs

- If $y_i^t - x_i^t$ is conserved, the profit from illegal logging is p^t at each unit of the forest.
- Expected penalty must be at least as large as the profit
- The cost of monitoring is thus $\alpha p^t (y_i^t - x_i^t)$ for some $\alpha \geq 0$. So,

$$u_i^t = \beta p^t x_i^t - \alpha p^t (y_i^t - x_i^t) + s_i^t,$$

- This is the model of Harstad and Mideksa '16
- (That paper also studies contracting with a subset of agents, and endogenizes institutions/(de)centralization. But the model is static..)
- In our setting, none of these two extensions do much of a difference in isolation

Robustness: The Crucial Assumptions

- Suppose $c_i = 0$ and $e_i = e$.

Proposition

- $\exists \underline{\alpha}$ s.t. if $\alpha < \underline{\alpha}$,
 - 1 The smallest is extracted first
 - 2 In steady state, $y^T < y_{FB}^T$ (first best)
 - 3 Speed of extraction is too fast
- $\exists \bar{\alpha}$ s.t. if $\alpha > \bar{\alpha}$,
 - 1 The largest is extracted first
 - 2 In steady state, $y^T > y_{FB}^T$ (first best)
 - 3 Speed of extraction is too slow

Robustness: The Crucial Assumptions

- The sufficient thresholds are:

$$\underline{\alpha} \equiv \beta \cdot \min_{z \in Z^t} \left\{ \frac{1 - \delta F'(z)}{[1 - \delta F'(F(z))] \cdot F'(z)} - 1 \right\},$$
$$\bar{\alpha} \equiv \beta \cdot \max_{z \in Z^t} \left\{ \frac{1 - \delta F'(z)}{[1 - \delta F'(F(z))] \cdot F'(z)} - 1 \right\}.$$

- Intuition: If α is large and $x_i^t \uparrow$, protection costs $\downarrow$, and agent j benefits
- The positive externality (on j 's outside option) is larger if y_j^{t+1} is large
- The principal minimizes j 's outside option: Thus, $x_i^t \downarrow$ if j is large
- Hence: Extract from the *largest* first!

Conclusions

- The world is likely to have to pay for the conservation of resources
- This is the first (?) paper studying contracting on resource depletion
- The first-best is to extract the least expensive/polluting resource first
- ① The equilibrium is to extract from the smallest stocks first
- ② Optimal contracts are highly asymmetric
- ③ Too little is conserved and extraction is too fast in equilibrium
- ④ Long-term contracts with delayed payments give more conservation
- Results are derived in a sales-driven model
- May be overturned in a protection-cost driven model
 - Conserve the largest coal field!
 - Conserve the smallest forest?