The Green Paradox
A Hotelling *Cul de Sac*

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Carbon Tax

- CO_2 emissions → climate change
- More or less proportional to fossil fuel use
- *Marginal damages* increase through time
- Conventional policy proposal:

  increasing Pigovian tax per unit (royalty)

The Hotelling Paradox

- Hotelling's rule: to maximize NPV, produce s.t. marginal net benefit rises at the interest rate
- Rising tax → revise this marginal calculation
- *Outcome*: ↑ present production & ↓ later
- Paths of p and q "tilted" w.r.t. original eqm.
- Paradox: tax *increases* current emissions
- High, decreasing tax?

Stock Effect

- The paradox holds for a Hotelling model in which marginal cost increases as a function of the depletion of reserves: Hans-Werner Sinn
- Considered to be general

Hotelling Equilibrium

- Sectorial: pools reserves; with some exceptions decisions made for the aggregate
- Paths *(q(t),p(t))* simultaneously determined

Shortcomings

1. no sunk capital (exploration & development)
2. no constraint to “tilting” output
3. all reserves aggregated for purposes of modeling the decisions

Simple Change

Industrial rather than Consumptive

1. Reserves distinct; decisions are made by separate firms for each reserve
2. Discrete, sunk investments → *q(0)*
3. *Natural decline* $q(t) = q(0)\exp(-a(K)t)$

   "Tilt", $-a$, given by geology and investment

Away from Hotelling

- Incentives apply to and decisions are made at individual reserves

a. Pigovian tax affects incentives, decisions
b. Partial equilibrium: given path *p(t)*
c. Simplified, simulated
d. Capital invested at start, *K*; price *P*

Present Values

- Expressions quite simplified: enhanced recovery
- To firm ($q(0) \propto K$)
- $V(K,T,\{\tau\}) = -E - PK$

$$+\sum\{p_t q_t - [aq_t + bK] - \tau_t q_t\}\, e^{-rt}$$

- Of carbon damages from emissions
- $D(K,T,\{\tau\}) = \sum d_t\, q_t\ e^{-r_d t}$, $r_d \neq r$?
- Of royalties
- $G(K,T,\{\tau\}) = \sum \tau_t q_t e^{-rt}$

Conditions

- Variable profits (in curly brackets) ≥ 0
- NPV to firm ≥ 0 (total sunk cost *E* + *PK* must be recovered from discounted net revenues)
- *Shadow* value of capacity *v(t)* > 0 on an interval (produce up to geological constraint):

$$P = \sum_{t=1}^{T} v(t)e^{-rt}$$

Variable & Fixed

- Variable (as royalty varies):

  initial extraction $q(0) = K$, investment; productive life of reserve T;

  ultimate recovery, $\int q(t)\, dt$

- Fixed:

  properties of initial reserve

Valid Comparisons?

- Recall: comparisons are of the tilt of the level of production and of emissions
- Increasing τ → paradox; decreasing not
- A lot of changes. What else must be held fixed to provide equal tax "effort"?

1. Share of rents $G(K,T,\{\tau\})/V(K,T,\{\tau\})$?
2. Total rents over positive paths of τ_t?
3. Government's take: $G(K,T,\{\tau\}) = \alpha V(K,T,\{0\})$?

The Choice (?)

- We choose no. 3, NPV of royalties (50% of social value gross of damages before royalty)
- Equal effort literally true of only one reserve for a given path of the royalty
- A good choice? There *is* no good choice:

  this is a problem with Hotelling model pinpointed by partial eqm. model

Predicted Effects of Royalty

- Reduction in exploration
- Decrease in investment and initial production
- Delay of investment in enhanced recovery
- Decreasing royalty has lower investment than increasing (as predicted), greater ultimate recovery (not predicted)
- Ultimate recovery increased for decreasing royalty and decreased for increasing royalty
- Life of reserve longer for decreasing royalty
- Rent to firm tends to be lower for decreasing royalty

Partial Weakness

- Decisions at reserve level: *partial* equilibrium
- Sectorial Equilibrium???
- IAMs need many strong assumptions
- Simpler: let price obey paradox's predictions, proceed as before
- Valid?

Partial Sectorial Model

- Guesses about price path
- Benchmark 1.5% increase in price with no tax
- Royalty ↑ at 3% → 2% ↑ in *p*
- Royalty ↓ at 3% → 1% ↑ in *p*
- Results broadly similar
- Company prefers rising royalty

Unexpected

- *Strong* green paradox: royalty → ↑ $D(K,T,\{\tau\})$
- Yes, if decreasing royalty and social $r_d = 0.014$ (Stern) while private $r = 0.08$:
- Why? Increase in ultimate production, slower but negligible discounting
- Should we discount at different rates?

CBA

- Many royalties fail a *cost-benefit* test

  DWL of royalty offsets (resource) gains from reducing carbon damages (environmental)

  – *royalties that pass: **increasing** royalty with low discounting of damages*

Paradox Unrealized?

- Royalty does not affect current production; does affect investments, new & enhanced
- Suppose minimal effect on *r* in g.e.
- Exploration decreases at each prospect
- Each new reserve has smaller investment
- Must be a large and continuing backward "tilt" of sunk cost at marginal exploration and development projects now facing a lower price
- Timing?

Efficient Policy

- Paradox meaningless when consider technology
- Likely the increasing royalty is superior: Pigovian, minimizes deadweight loss
- Recent decrease in price standard:

  high price → change in technology → entry