The Green Paradox and The Misapplication of the Economics of Exhaustible Resources

Robert D. Cairns
Department of Economics and Cireq
McGill University

climate change → reduce consumption of fossil fuels esp oil

method favoured by many economists: tax on emissions of CO_2

marginal harm ↑ → tax ↑

salutary?

"green paradox": incentive of tax may be to shift production toward the present

increase in damages SR & MR

even expectation of a tax to be instituted in the future

subsidy to alternative forms of energy

economics of exhaustible resources: Hotelling’s rule

price net of marginal costs, including marginal taxes, rises at r

green paradox a direct application of Hotelling’s rule

timing of extraction and use

tax changes relative net values of a unit of oil at different future dates

→ tilt production toward present

greater emissions in present and near present induced

at expense of emissions in far future

by then other means to attack the climate problem

Paradoxically, the tax may exacerbate climate change in present

only very limited relief in the future

relevant theoretic issue is recast by climate change:

now efficient timing of a tax

instead of the equity and efficiency of Pigovian tax

policy issue: whether and how plays out

fundamental question: provenance of SR increases in output

doubts about the analysis & applicability of Hotelling's rule

Hotelling's (1931) model has five major insights:

- Exhaustible resources are a form of capital
- Price determined in dynamic equilibrium: regulates flow and holding as assets
- Timing of decisions is central
- Usual market failures, monopoly & externality
- Exhaustibility not special market failure; competitive markets "work"

striking analytic result is Hotelling's rule:

price net of marginal cost at r

under assumptions of model, rule is mathematically incontrovertible economic reasoning even more striking

type-one Hotelling model of an exhaustible resource:

extraction cost $c(q)$ increasing and convex

Solow 1974: rearrange extraction s.t. p.v. of marginal profit equalized

ultimately, $p(t) - c'(q(t)) = \lambda e^{rt}$, Hotelling's rule, arbitrage condition often assumed that marginal cost is constant

assumption allows for developing sharp mathematical results

includes early insights of paradox by Sinclair (1992) and Ulph & Ulph (1994)

Hotelling also considered a type-two model:

cost *C(q,Q)*: increasing, convex function of q; decreasing, convex function of *Q*

less sharp theoretic results than a type-one:

still arbitrage but a more complicated rule involves

$$\int_t^T \frac{\partial C(q,Q)}{\partial Q} e^{-r(T-t)} dt$$

harder to work with but considered more realistic

allow for extraction costs at *T* so high that leave some of the resource

$C(q,Q)$: workhorse of empirical research since the late 1970s

several theoretic analyses too

similar for green paradox

Both $c\,(q)$ & $C\,(q,Q) \Rightarrow$ any level of q possible at current MC

nature of arbitrage: output can be shifted at will over time

no impediment to tilting output toward the present

Sinn (2008): arbitrage between adjacent periods

$\rightarrow$ green paradox

Let $C(q,Q) = g(Q)q$: only slightly special

let the market price be P

consider alternative extraction policies

1. extract a unit of resource and invest for one period:

$$[P(t) - g(Q)] + r[P(t) - g(Q)]$$

2. extract after one period (neglect change in Q):

$$P(t+1) - g(Q)$$

Arbitrage renders the two equal at each time t:

$$\frac{\Delta P(t)}{P(t) - g(Q)} = r$$

Sinn proposes an unfamiliar tax to minimize algebra:

Cash-flow tax grows such that net cash flow per unit decreases at rate δ:

$$1 - \tau(t) = \frac{1 - \tau(0)}{(1 + \delta)^t}$$

equilibrium condition:

$$\frac{1-\tau(0)}{(1+\delta)^{t}}\left[P(t)-g(Q)\right](1+r)=\frac{1-\tau(0)}{(1+\delta)^{t+1}}\left[P(t+1)-g(Q)\right]$$

modified rule:

$$\frac{\Delta P(t)}{P(t)-g(Q)}=r+\delta+r\delta\approx r+\delta$$

If $\delta = 0$ (constant tax), neutral

If $\delta > 0$, ΔP greater than if $\delta = 0$

assumptions $\Longrightarrow$ reserves eventually exhausted

at exhaustion price must be the intercept of demand

since price rises faster with the increasing tax, starts out lower

$\Longrightarrow$ $q(t)\uparrow$ and reserve used up earlier economics:

rising tax changes the relative gains to the producer over the life of the reserve

→ current extraction comparatively more attractive

lower current price.

→ global warming exacerbated

green paradox: taxing emissions → greater emissions

better? initially very high but deceasing tax others authors have studied the paradox

- different conditions from those postulated by Sinn
- still within Hotelling framework

have qualified his results

Hotelling's Rule:

1. mathematically incontrovertible
2. subject to much controversy
3. practitioners: decisions supposed to implement the rule
4. deny its relevance
5. challenges from academia

Livernois: the evidence does “not necessarily invalidate the conceptual message of

the Hotelling Rule”

conviction “that mining firms think not just of the present but about the future,

and that they wish to maximize the value of their assets” thrust of Hotelling's message not that firms max n.p.v.

max n.p.v. is initial hypothesis about conduct in any industry

Hotelling's rule is

1. specific to exhaustible resources

2. foundation for thinking about dynamics of resource price

Livernois describes Hotelling's rule as

"a condition of intertemporal arbitrage that ensures that the last unit extracted in
any time period earns the same return (in present value terms)"

arbitrage: ability to move production freely across time

Livernois finds that

- "overall one cannot conclude that the Hotelling Rule has been a significant force"
- "other factors...have had a more significant influence on the evolution of prices"

the arbitrage condition has not received broad support from empirical research

squares with casual observation of oil price since 1970, esp since 2001

arbitrage may not be being realized. Why?

key assumption: output can be rearranged as desired

C(q,Q) not a valid representation of the technology

high up-front cost in drilling wells → output capacity

Campbell (1980), Crabbé (1982) and Lasserre (1985)

installed capacity is usually not changed for a significant period

output in the early years is at the level of capacity oil industry specifically:

1. period of capacity production

2. productivity of a well decreases through natural decline

output restricted by the more stringent of capacity and natural factors

- Hotelling models are short-run models: neglect decision to invest
- also neglect that technology does not allow unlimited output
- neglect other, natural limits to production

free arbitrage fundamental to Hotelling analysis not available

For analysis of the effects of policy, long-run analysis is required.

Technological models:

- reserve-based rather than sector-based
- conditions of production at the individual reserve
- behavior of sector an aggregate of behavior of individual producers

formal models:

1. stress extraction

2. less about exploration

3. less still about development

reason: as move vertically backwards, more complicated and intricate

all downstream features required in a valid model

industry cannot be fully represented in formal models

less formal, economic analysis for bridges and extensions technology: oil produced from underground reservoirs under great pressure

well drilled into the formation allows pressure to be released

with it the oil and gas

natural drive: pressure is sufficient to produce the oil, at declining rates if pressure not great enough, pumps at surface to lift the oil

secondary production: injection wells at the periphery of the reservoir

valuable product is oil

scarce natural or artificial instrument of production is pressure

augmentation of pressure in various ways producing property: all investments made; short run

realistic counterpart to Hotelling analysis

oil driven to the surface by pressure, $P(t)$

declines by natural decline at rate a: $dP/dt = -aq$

output depends on pressure: $q \leq \pi P$

$\rightarrow q\,(t) = q\,(0)\,e^{-at}$

abandoned at T; reserve is $\int_0^T q(t)\,dt = q(0)\left(1 - e^{-aT}\right)/a$

Let net price $\nu(t)$ grow at $g < r$.

Value of the reserve:

$$\int_0^T \left[\nu(0)\,e^{gt}\right]\left[q(0)\,e^{-at}\right]e^{-rt}dt = \nu(0)\,\frac{a}{a+r-g}\,\frac{1-e^{-(a+r-g)T}}{1-e^{-aT}} < \nu(0)\,R(0)$$

Production fully determined by geological features

formal optimization is trivial

economic meaning is not trivial

at an individual reservoir and hence for the whole industry,

prediction of the

Hotelling model does not hold

mathematical reason: positive shadow value of pressure

adjoint variable of constraint on output

pressure is a scarce resource: increase in pressure allows

operator to extract faster

portion of the net price, $\nu(t)$, attributed to pressure

holds under uncertainty

Hotelling rule does not hold because output is constrained

therefore, no change in output as a result of a tax

(unless the tax is so high as to put the firm out of business).

no green paradox here

some reserves are known but “held on the shelf” for later development

pressure constraint can be alleviated, to an extent, by investment

hasten development of reserves → green paradox?

optimal development when the *rate of increase of present value* falls to *r*

choice of timing is that of original investment

coincident with choice of the level of investment

investment “locks in” the maximal rate &, in practice, actual rate of production tax on emissions affects all units of output throughout the production path

effect is on timing and level of initial investment

may well be earlier or later, depending on prediction of the unfolding of the market

rate of change n.p.v. not easy to predict, subtle given choice of timing of investment Adelman considers the

choice of the level of

investment and hence the choice of pressure

investment the product of

1. “investment factor” k

2. decline factor a (determined by choice of level of investment

3. initial level of output $q(0)$:

$$\max_{q,a} \int_0^T \nu(t)\, q(t)\, e^{-rt} dt - kaq(0)$$

cubic equation for a with a single real root → k unique

depends on the path of net price

↓ anticipated net prices → capacity ↓

decline here starts immediately

secondary and tertiary methods → decline not immediate

Cairns (1998, 2001) confirms Adelman's result:

- investment determines level of production
- at most properties, output constant over a certain period early on
- marginal cost of capital = discounted value of its shadow price
- shadow value of investment must be positive on a non-degenerate interval
- positive shadow value $\Rightarrow$ level of output is constrained

at any time at any producing property in the oil industry, output is constrained by

the most stringent of several constraints

short-term increase of the green paradox not possible without investment increase in capacity not profitable in original equilibrium

(would have been made)

tax reduces the profitability of the investment: reduces net price of each unit

moreover, green paradox ⇒ p and hence $\nu\downarrow$

no reason to postulate investment in response to the tax or increase in output

Conceivably may be investment earlier at some properties

may, to an extent, offset a lower capacity level

timing responds to the rate of change of n.p.v. and is subtle

Uncertainty about the tax may delay investment

Exploration a “set-up” cost

sunk cost but no constraint on arbitrage of output

emissions tax shifts distribution of returns from exploration to the left

tax increasing through time → continual shift to the left increase or a decrease in exploration may result

e.g. “black-gold rush” to realize the value of exploration provinces earlier

or a holding back of exploration because of lower returns to sunk

investment

current increase in exploration depends on existence of spare capacity in drilling rigs and in exploration professionals

in equilibrium, spare capacity is low:

investments are made to reap quasi rents, not to sit idle in anticipation of a tax that lowers scarcity and quasi rents

long lead time from the start of exploration through development to production → relevant changes between one and two decades forward knowledge - in basic & applied research and in the training of professionals

long lead times

likely embodied in new vintages of capital

→ limited effect on wells in service or under development

returns likely to be reduced

professionals may shy away from training in an industry that is expected to be

subject to increasing tax, reduced rents, mandated substitutes

difficult to perceive incentive to investment in refining & transportation

Hotelling's rule is a product of a simple model

basic insight borne out

oil industry is too complicated and varied to be fit into a simple projection

Hotelling models assume

1. preponderance of an exhaustibility constraint

2. free allocation of resources over time

reality:

1. exhaustibility peripheral

2. dominating constraint is that allocation is capped

Technological models have a qualitative break

Hotelling models: decision at each instant about flow

technological models:

- decisions about flows atrophied
- extraction requires combination of reserve & fixed capital
- basic decisions infrequent, about investment
- capacity predetermines & constrains flows
- subject to natural conditions.

Models of several important features of oil production must be stitched together

Some are becoming more fully understood.

Others have not yet been subject to rigorous research.

green paradox at best not proven

not possible to prove given current limitations of mathematical analysis present paper: many factors inimical to the predictions of the paradox should not hesitate to implement incentive-based policies