Resource conservation and directed R&D: Multiple trajectories?

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Non renewable resources and the long-run

- Necessary conditions to overcome the limits :
  Dasgupta and Heal (1974), Solow (1974), Stiglitz (1974)
  (*i*) a sufficiently high potential for substituting capital for non-renewable resources,
  (*ii*) a sufficiently high pace of total factors productivity growth
- Endogenous growth theory applied to environmental policy
  Bovenberg & Smulders (1995), Smulders (1995), Aghion & Howitt(1998)
- Technical change and the scarcity of natural resources
  - non directed technical progress
    Sholz & Ziemes (1999), Schou (2000), van Zon & Yetkin (2003)
  - directed technical progress with renewable resources
    Smulders & de Nooij (2003), Grimaud & Rougé (2007)
  - directed technical progress with non renewable resources
    Di Maria & Valente (2008), André & Smulders (2008), Eriksson (2008), Hart (2008)

Motivation

- Technical change targeted on non renewable resources
  - R&D labs target improvements in efficiency of resource use
  - Resource owners exhaust efficiently the resource stock

  two forward looking activities
  - R&D labs are concerned by the expected market size (Schumpeter)
  - Resource (Mine) owners are concerned by expected demand (Hotelling), thus technology

  There is (strategic) interaction
  - R&D labs' decisions affect the value of the mine
  - Mine-owners' decisions affect the return on R&D investment

Motivation

Under what conditions there may emerge multiple equilibria ?

- A High equilibrium with strong R&D investment and resource conservation (i.e. slow exhaustion)
- A Low equilibrium with little R&D investment and rapid exhaustion of the resource
- Necessary condition : strategic complementarity,
    - i.e. ‘investment’ of one player increases the payoff from ‘investment’ for the other player

Sketch of argument

High equilbrium

- high R&D today

$\Rightarrow$ improved resource efficiency tomorrow

$\Rightarrow$ demand for the resource $\nearrow$ (?)

$\Rightarrow$ mine-owners delay extraction

$\Rightarrow$ large market size for innovators

$\Rightarrow$ high return on innovation

$\Rightarrow$ high R&D today

Sketch of argument

Low equilibrium

- low R&D today

$\Rightarrow$ no resource efficiency improvement tomorrow

$\Rightarrow$ demand for the resource $\searrow$ (?)

$\Rightarrow$ mine-owners deplete fast

$\Rightarrow$ small market size for innovators

$\Rightarrow$ low return on innovation

$\Rightarrow$ low R&D today

Outline

- A simple 2x2x2 game
    - setup and assumptions
    - The agents's problem
    - The game
    - Necessary conditions for two equilibria
- Discussion

A simple 2x2x2 game

- 2 periods :
  - 0 today
  - 1 in 20 years
- 2 players :
  - the Mine-owner
  - the R&D lab
- 2 actions :
  - the Mine-owner sells

$$F_0 = \{\underline{S}, \bar{S}\} \text{ , } F_1 = \{\underline{S}, \bar{S}\} \quad \textit{and} \quad F_0 + F_1 = \underline{S} + \bar{S} \equiv S \quad ; \quad \theta \equiv \frac{\bar{S}}{\underline{S}}$$

  - the R&D lab invests or not (cost K), technology index :

$$a_0 = \underline{a} \quad , \quad a_1 = \{\underline{a}, \bar{a}\} \quad ; \quad \bar{a} = \gamma \underline{a} \text{ with } \gamma > 1$$

A simple 2x2x2 game

(Innocent) assumptions

A1. players act as price-takers ;

A2. players are risk-neutral ;

A3. the real rate of interest, *r*, is exogenous ;

A4. there is no uncertainty in the innovation process.

A simple 2x2x2 game

(Crucial) assumptions

A5. Sector output characterized by CRS wrt primary inputs F, thus IRS globally :

$$Y_t \equiv a_t F_t$$

Four possible output levels :

$$Y^L = \underline{aS} \qquad Y^N = \bar{a}\underline{S} = \gamma Y^L$$

$$Y^M = \underline{a}\bar{S} = \theta Y^L \qquad Y^H = \bar{a}\bar{S} = \gamma\theta Y^L$$

$\Rightarrow$ four possible levels of the revenue 'function' VA :

$$VA^i \equiv p_{Y^i} Y^i \text{ with} i \in \{L, N, M, H\}$$

A simple 2x2x2 game

(Crucial) assumptions

A6. $VA \equiv p_Y Y$ function increasing quasi-concave :

$$\frac{\partial VA}{\partial Y} > 0 \quad , \quad \frac{\partial^2 VA}{\partial Y^2} \leq 0$$

A7. Exogenous sharing rule $\beta \in (0, 1)$:

$$VA^i = \underbrace{\beta p_{Y^i} Y^i}_{\text{mine-owner}} + \underbrace{(1-\beta)\, p_{Y^i} Y^i}_{\text{patent-holder}}$$

A7. Simultaneous game :
actions are based on expectations not on observed current variables

The Mine-owner problem

Choice of $x \in \{0, 1\}$ to maximize

$$E\left[p_{F0}\underline{S} + \frac{p_{F1}}{1+r}\underline{S} + p_{F0}\left(\bar{S} - \underline{S}\right)(1-x) + \frac{p_{F1}}{1+r}\left(\bar{S} - \underline{S}\right)x\right]$$

Solution

$$x = \begin{cases} 0 \text{ , sell } F_0 = \bar{S} & \text{if } E\left(\frac{p_{F1}}{p_{F0}}\right) < 1+r \\ 1 \text{ , sell } F_0 = \underline{S} & \text{if } E\left(\frac{p_{F1}}{p_{F0}}\right) > 1+r \end{cases}$$

- The Hotelling rule
- Expected prices depend on expected technical progress

$$p_{Ft}F_t \equiv \beta VA_t \quad \Rightarrow \quad p_{Ft} = \beta p_{Yt} a_t$$

The R&D lab

Choice of $y \in \{0, 1\}$ to maximize

$$E\left[0\,(1-y) + \left(-K + \frac{1}{1+r}V\right)y\right]$$

Solution

$$y = \begin{cases} 0\text{ , do not invest} & \text{if } E\,(V) < (1+r)\,K \\ 1\text{ , invest} & \text{if } E\,(V) > (1+r)\,K \end{cases}$$

- where $V = (1-\beta)\,VA_1$
- depends on the mine-owner choice of F_1 since

$$V = (1-\beta)p_{Y1}\,\bar{a}F_1$$

The game

		Mine-owner	
		deplete $x = 0$	conserve $x = 1$
R&D lab	do not invest $y = 0$	$0, v$	$0, u$
	invest $y = 1$	q, t	s, w

Multiple equilibria ?

- $v > u$ trivial if $r > 0$: conservation is not worth without R&D

- $q < 0$ R&D is not worth without resource conservation

$$VA^{N} < \frac{1+r}{1-\beta}K$$

- $s > 0$ R&D is worth with resource conservation

$$VA^{H} > \frac{1+r}{1-\beta}K$$

- Satisfied for some $K/(1-\beta)$

Multiple equilibria ?

- $w > t$ Conservation is profitable with technical progress

$$w \equiv \beta \left(VA^L + VA^H/(1+r) \right) \quad > \quad t \equiv \beta \left(VA^M + VA^N/(1+r) \right)$$

$$VA^H - VA^N > (1+r) \left(VA^M - VA^L \right)$$

Also coherence with Hotelling rule is needed

- resource exhaustion is rational in the LOW case

$$\frac{p_{F1}}{p_{F0}} < 1 + r \quad \Leftrightarrow \quad VA^M > \frac{\theta}{1+r} VA^L$$

- resource conservation is rational in the HIGH case

$$\frac{p_{F1}}{p_{F0}} > 1 + r \quad \Leftrightarrow \quad VA^H > \theta \, (1+r) \, VA^L$$

where $\theta \equiv \bar{S}/\underline{S}$

Multiple equilibria ? Pattern

Conditions to be satisfied

(1) $VA^H - VA^N > (1 + r)\left(VA^M - VA^L\right)$

(2) $VA^M > \frac{\theta}{1+r} VA^L$

(3) $VA^H > \theta\,(1 + r)\, VA^L$

where VA is assumed increasing concave in Y and

$$Y^L = \underline{aS} \quad ; \quad Y^N = \gamma Y^L \quad ; \quad Y^M = \theta Y^L \quad ; \quad Y^H = \gamma\theta Y^L$$

Multiple equilibria ? The magnifying effect

Conditions to be satisfied

(1) $VA^H - VA^N > (1+r)\left(VA^M - VA^L\right)$

(2) $VA^M > \frac{\theta}{1+r} VA^L$

(3) $VA^H > \theta\,(1+r)\,VA^L$

Condition (1) : *Magnification* of R&D on resource conservation

$$VA^H - VA^N > VA^M - VA^L \quad \Rightarrow \quad \frac{\partial^2 VA}{\partial F \partial a} > 0$$

Conservation must be much more valuable to the sector with technical progress than without it

Multiple equilibria ? Innovation opportunity

Conditions to be satisfied

(1) $VA^H - VA^N > (1+r)\left(VA^M - VA^L\right)$

(2) $VA^M > \frac{\theta}{1+r} VA^L$

(3) $VA^H > \theta\,(1+r)\,VA^L$

Conditions (3) and (1) : *Large innovation opportunity*

$$\gamma > 1 + r$$

The Hotelling rule in the High equilibrium

$$\frac{p_{F1}}{p_{F0}} > (1+r) \quad \Leftrightarrow \quad \frac{VA^H}{VA^M} > (1+r)$$

$$\Leftrightarrow \quad 1 + r < \gamma \left.\frac{p^H_{Y1}}{p^L_{Y0}}\right|_{\text{high eq.}} < \gamma$$

Potential technical progress stronger than average

Multiple equilibria ? Linear VA

Suppose VA is linear (p_Y constant $\Rightarrow$ $VA = kY$)

(1) $\frac{VA^H - VA^N}{VA^M - VA^L} > (1+r) \quad \Leftrightarrow \quad \frac{(\theta-1)\gamma Y^L}{(\theta-1) Y^L} > (1+r)$

(2) $VA^M > \frac{\theta}{1+r} VA^L \quad \Leftrightarrow \quad \theta Y^L > \frac{\theta}{1+r} Y^L$

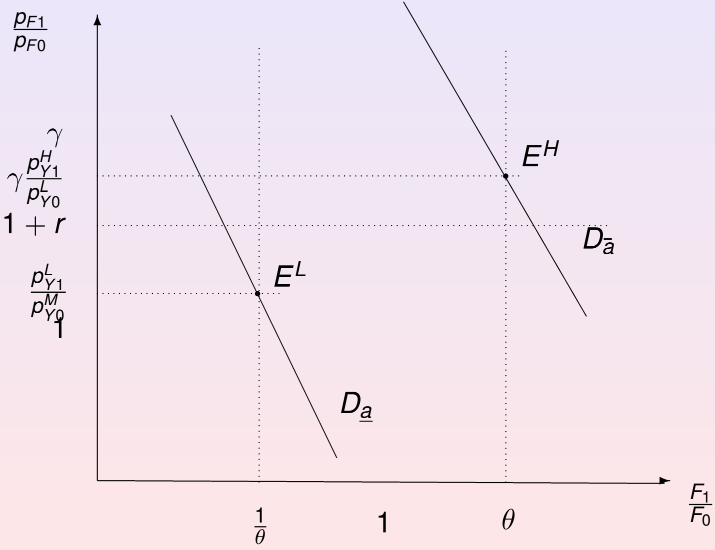
(3) $VA^H > \theta (1+r) VA^L \quad \Leftrightarrow \quad \gamma\theta Y^L > \theta (1+r) Y^L$

- Sufficient conditions for multiplicity

$$\gamma > 1 + r > 1$$

- By continuity... for VA not too concave multiplicity can emerge

Discussion : equilibrium relative bias



Discussion : CGE modeling

- Nested CES production functions

$$
\begin{aligned}
E &= g(Y,R) \equiv \left(Y^{\frac{\sigma-1}{\sigma}} + R^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \\
Q &= h(E,L) \equiv \left(E^{\frac{\psi-1}{\psi}} + L^{\frac{\psi-1}{\psi}} \right)^{\frac{\psi}{\psi-1}}
\end{aligned}
$$

- Typical assumption $\psi < 1$
- The five necessary conditions for multiple equilibria can be satisfied if Y can steal the market from R, i.e. $\sigma > 1$
- Application : $\sigma = 2$, $\psi = .75$, $L = 1000$, $R = 100$, $K = 7$, $\beta = .1$ $\underline{S} = 10$, $\theta = 2$, $\underline{a} = 1$, $\gamma = 1.8$, $r = .25$

Discussion : empirical implications

- Conservation pays off under technical progress :

$$\frac{\partial^2 VA}{\partial F \partial a} > 0$$

- Do improvements in technology increase the demand for the resource ?
  The rebound effect of energy-efficiency policies
- $\gamma > 1 + r$, important potential technological progress

Discussion : policy

- Pareto rankable outcomes
- Hysteresis and ”path” dependance
- Diffusion of information and coordination

Discussion : extensions

- Robustness check wrt
  - continuous actions ($\sim \theta$ and γ endogenous)
  - time horizon
  - repeated interaction
  - supply of R
- Scope for multiplicity in a vintage model ?

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